Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, D.C.

TSO-C117b

Effective
Date: 3/27/18

Technical Standard Order

Subject: Airborne Windshear Warning And Escape Guidance Systems For Transport Airplanes

1. PURPOSE. This technical standard order (TSO) is for manufacturers applying for a TSO authorization (TSOA) or letter of TSO design approval (LODA). In it, we (the Federal Aviation Administration, (FAA)) tell you what minimum performance standards (MPS) your airborne windshear warning and escape guidance systems for transport category airplanes must first meet for approval and identification with the applicable TSO marking. This TSO defines performance, functions, and features for systems providing windshear warning and escape guidance commands based upon sensing the airplane's encounter of such phenomena. It is not applicable to systems that look ahead to sense windshear conditions before encountering the phenomenon nor to systems using atmospheric and/or other data to predict the likelihood of a windshear alert.

Appendix 1 of this TSO describes the MPS for the airborne windshear warning and escape guidance systems for transport category airplanes. Appendix 2 of this TSO describes the wind field models used to evaluate the performance of the windshear warning and escape guidance system. Appendix 3 of this TSO describes the conversion of the velocity equations in Appendix 2 to rectangular coordinates. Appendix 4 of this TSO contains data defining the Dryden turbulence model and discrete gust model used in conducting the windshear alert tests. Appendix 5 of this TSO describes shear intensity. Appendix 6 of this TSO provides a sample computer listing for a simplified aircraft simulation model for evaluating the effectiveness of various guidance schemes.

2. APPLICABILITY. This TSO affects new applications submitted after its effective date.

a. TSO-C117a will also remain effective until September 27, 2019. After this date, we will no longer accept applications for TSO-C117a.

b. Airborne windshear warning and escape guidance system approved under a previous TSOA may still be manufactured under the provisions of its original approval.

3. REQUIREMENTS. New models of airborne windshear warning and escape guidance systems identified and manufactured on or after the effective date of this TSO must meet the MPS qualification and documentation requirements set forth in appendix **1**.

a. Functionality. This TSO's standards apply to equipment intended to identify the presence of windshear once the phenomenon is encountered and provide the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter.

b. Failure Condition Classifications.

(1) Failure of the function defined in paragraph **3.a** resulting in unannunciated malfunction or missed windshear detection is a major failure condition.

(2) Loss of the function defined in paragraph **3.a** is a minor failure condition.

(3) Design the system to at least these failure condition classifications.

c. Functional Qualification. Demonstrate the required functional performance under the test conditions in appendix **1** of this TSO.

d. Environmental Qualification. Demonstrate the required performance under the test conditions in appendix **1**, paragraph **4.c** of this TSO using standard environmental conditions and test procedures appropriate for airborne equipment. You may use different standard environmental conditions and test procedures than specified in RTCA/DO-160G provided the standard is appropriate for the airborne windshear warning and escape guidance system.

> **Note:** The use of RTCA/DO-160D (with Changes 1 and 2 only, without Change 3 incorporated) or earlier versions is generally not considered appropriate and will require substantiation via the deviation process as discussed in paragraph **3.g** of this TSO.

e. Software Qualification. If the article includes software, develop the software according to RTCA, Inc., document, RTCA/DO-178C, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 13, 2011, including referenced supplements as applicable, to at least the software level consistent with the failure condition classification defined in paragraph **3.b** of this TSO. You may also develop the software according to RTCA, Inc., document RTCA/DO-178B, dated December 1, 1992, if you follow the guidance in AC 20-115D, *Airborne Software Development Assurance Using EUROCAE ED-12() and RTCA DO-178(),* dated July 21, 2017, or latest revision.

f. Electronic Hardware Qualification. If the article includes complex custom airborne electronic hardware, then develop the component according to RTCA, Inc., Document RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*, dated April 19, 2000, to at least the design assurance level consistent with the failure condition classification defined in paragraph **3.b** of this TSO. For custom airborne electronic hardware determined to be simple, DO-254, paragraph 1.6 applies.

g. Deviations. We have provisions for using alternate or equivalent means of compliance with the criteria in the MPS of this TSO. If you invoke these provisions, you must show that your equipment maintains an equivalent level of safety. Apply for a deviation pursuant to 14 CFR § 21.618.

4. MARKING.

a. Mark at least one major component permanently and legibly with all of the information in 14 CFR § 45.15(b).

b. If the article includes software and/or airborne electronic hardware, then the article part numbering scheme must identify the software and airborne electronic hardware configuration. The part numbering scheme can use separate, unique part numbers for software, hardware, and airborne electronic hardware.

c. You may use electronic part marking to identify software or airborne electronic hardware components by embedding the identification within the hardware component itself (using software) rather than marking it on the equipment nameplate. If electronic marking is used, it must be readily accessible without the use of special tools or equipment.

5. APPLICATION DATA REQUIREMENTS. You must give the FAA Aircraft Certification Office (ACO) manager responsible for your facility a statement of conformance, as specified in 14 CFR § 21.603(a)(1) and one copy each of the following technical data to support your design and production approval. LODA applicants must submit the same data (excluding paragraph **5.g**) through their civil aviation authority.

a. Manuals containing the following:

(1) Operating instructions and article limitations sufficient to describe the equipment's operational capability.

(2) Detailed description of any deviations.

(3) Installation procedures and limitations sufficient to ensure that the airborne windshear warning and escape guidance system, when installed according to the installation or operational procedures, still meets this TSO's requirements. Limitations must identify any unique aspects of the installation. The limitations must also include a note with the following statement:

> "This article meets the minimum requirements of TSO-C117b. Installation of this article requires separate approval."

(4) For each unique configuration of software and airborne electronic hardware, reference the following:

(a) Software part number, including revision and design assurance level,

(b) Airborne electronic hardware part number including revision and design assurance level, and

(c) Functional description.

(5) A summary of the test conditions used for environmental qualifications for each component of the article. For example, a form as described in RTCA/DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment,* Appendix A.

(6) Schematic drawings, wiring diagrams, and any other documentation necessary for installation of the airborne windshear warning and escape guidance system.

(7) By part number list of replaceable components that make up the airborne windshear warning and escape guidance system. Include vendor part number cross-references, when applicable.

b. Instructions covering periodic maintenance, calibration, and repair, to ensure that the airborne windshear warning and escape guidance system continues to meet the TSO approved design. Include recommended inspection intervals and service life, as appropriate.

c. If the article includes software: a plan for software aspects of certification (PSAC) software configuration index, and a software accomplishment summary.

d. If the article includes simple or complex custom airborne electronic hardware: a plan for hardware aspects of certification (PHAC), a hardware verification plan, top-level drawing, and hardware accomplishment summary (or similar document, as applicable).

e. A drawing depicting how the article will be marked with the information required by paragraph **4** of this TSO.

f. Identify functionality contained in the article not evaluated under paragraph **3** of this TSO (defined as non-TSO functions). Non-TSO functions can be accepted in parallel with the TSOA. For those non-TSO functions to be accepted, you must declare these functions and include the following information with your TSO application:

(1) Description of the non-TSO function(s), such as performance specifications, failure condition classifications, software, hardware, and environmental qualification levels. Include a statement confirming that the non-TSO function(s) do not interfere with the article's compliance with the requirements of paragraph **3**.

(2) Installation procedures and limitations sufficient to ensure that the non-TSO function(s) meets the declared functions and performance specification(s) described in paragraph **5.f.(1).**

(3) Instructions for continued performance applicable to the non-TSO function(s) described in paragraph **5.f.(1).**

(4) Interface requirements and applicable installation test procedures to ensure compliance with the non-TSO function(s) performance data defined in paragraph **5.f.(1).**

(5) Test plans and analysis, as appropriate, to verify that the performance of the hosting TSO article is not affected by the non-TSO function(s).

(6) Test plans and analysis, as appropriate, to verify that the function and performance of the non-TSO function(s) as described in paragraph **5.f.(1).**

g. The quality manual required by 14 CFR § 21.608, including functional test specifications. The quality system must ensure that you will detect any change to the approved design that could adversely affect compliance with the TSO MPS and reject the article accordingly. Applicants who currently hold TSOAs must submit revisions to the existing quality manual as necessary (not required for LODA applicants).

h. A description of your organization as required by 14 CFR § 21.605.

i. Material and process specifications list.

j. A list of all drawings and processes (including revision level) that define the article's design.

k. Manufacturer's TSO qualification report showing results of testing accomplished according to paragraph **3.c** of this TSO.

6. <u>MANUFACTURER DATA REQUIREMENTS</u>. Besides the data given directly to the responsible ACO, have the following technical data available for review by the responsible ACO:

> **Note:** The following data for a LODA applicant may be made available for review through its Civil Airworthiness Authority (CAA). Refer to the applicable bilateral agreement for specific details regarding access to this data.

a. Functional qualification specifications for qualifying each production article to ensure compliance with this TSO.

b. Article calibration procedures.

c. Schematic drawings.

d. Wiring diagrams.

e. Material and process specifications.

f. The results of the environmental qualification tests conducted according to paragraph **3.d** of this TSO.

g. If the article includes software, the appropriate documentation defined in RTCA/DO-178B or RTCA/DO-178C specified in paragraph **3.e** of this TSO, including all data supporting the applicable objectives in Annex A, *Process Objectives and Outputs by Software Level* of DO-178B or DO-178C.

h. If the article includes complex custom airborne electronic hardware, the appropriate hardware life-cycle data in combination with the design assurance level, as defined in RTCA/DO-254, Appendix A, Table A-1. For simple custom airborne electronic hardware, the following data are required: test cases or procedures, test results, test coverage analysis, tool assessment and qualification data, and configuration management records, including problem reports.

i. If the article contains non-TSO function(s), you must also make items **6.a** through **6.h** available as they pertain to the non-TSO function(s).

7. FURNISHED DATA REQUIREMENTS.

a. When furnishing one or more articles manufactured under this TSO to one entity (such as an operator or repair station), provide one copy or online access to the data in paragraphs **5.a** and **5.b** of this TSO. Add any other data needed for the proper installation, certification, use, or continued compliance with the TSO, of the airborne windshear warning and escape guidance system.

b. If the article contains declared non-TSO function(s), include one copy of the data in paragraphs **5.f.(1)** through **5.f.(4)**.

c. If the article contains software, include one copy of the Open Problem Report (OPR) summary to type certification, supplemental type certification, or amended type certification design approval holders.

8. HOW TO GET REFERENCED DOCUMENTS.

a. Order RTCA documents from RTCA Inc., 1150 18th Street NW, Suite 910, Washington, D.C. 20036. Telephone (202) 833-9339, fax (202) 833-9434. You can also order copies online at www.rtca.org.

b. Order copies of 14 CFR parts 21 and 45 from the Superintendent of Documents, Government Printing Office, P.O. Box 979050, St. Louis, MO 63197. Telephone (202) 512-1800, fax (202) 512-2104. You can also order copies online at www.gpo.gov.

c. You can find a current list of TSOs and advisory circulars at http://rgl.faa.gov/. You will also find the TSO Index of Articles at the same site.

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APPENDIX 1
FEDERAL AVIATION ADMINISTRATION MINIMUM PERFORMANCE STANDARD FOR AIRBORNE WINDSHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS FOR TRANSPORT AIRPLANES

1. PURPOSE. This appendix establishes the Minimum Performance Standards (MPS) for the airborne windshear warning and escape guidance systems for transport category airplanes.

2 SCOPE. The scope of this appendix is to provide minimum performance standards for your airborne windshear warning and escape guidance systems for transport category airplanes. All paragraph references cited herein are in reference to this appendix only.

This TSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this TSO. In addition to windshear warning criteria, this TSO provides criteria applicable to systems that provide optional windshear caution alert capability. Windshear escape guidance is provided to assist the pilot in obtaining the desired flight path during such an encounter.

3. DEFINITION OF TERMS.

a. Airborne Windshear Warning System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomena is encountered and provides the pilot with timely warning. The system may include both windshear warning and windshear caution alerts. A warning device of this type does not provide escape guidance information to the pilot to satisfy the criteria for warning and flight guidance systems.

b. Airborne Windshear Warning and Escape Guidance System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomenon is encountered and provides the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter. This system may include both windshear warning and windshear caution alerts.

c. Airborne Windshear Auto Recovery System. A device or system which integrates or couples autopilot and/or autothrottle systems of the aircraft with an airborne windshear flight guidance system.

d. Airborne Windshear Escape Guidance System. A system which provides the crew with flight guidance information to improve the recovery probability once encountering a windshear phenomenon.

e. Failure. The inability of a system, subsystem, unit, or part to perform within previously specified limits.

f. False Warning or Caution. A warning or caution which occurs when the windshear warning or caution threshold of the system is not exceeded.

g. Nuisance Warning or Caution. A warning or caution which occurs when a phenomenon is encountered, such as turbulence, which does not, in fact, endanger the aircraft because of the duration of subsequent change of the windshear magnitude.

h. Recovery Procedure. A vertical flight path control technique used to maximize recovery potential from an inadvertent encounter with windshear.

i. Severe Windshear. A windshear of sufficient intensity and duration that exceeds the performance capability of a particular aircraft type. This would likely cause inadvertent loss of control or ground contact if the pilot did not have information available from an airborne windshear warning and escape guidance system which meets the criteria of this TSO.

j. Windshear Caution Alert. An alert triggered by increasing performance conditions which is set at a windshear level requiring immediate crew awareness and likely subsequent corrective action.

k. Windshear Warning Alert. An alert triggered by decreasing performance conditions which is set at a windshear level requiring immediate corrective action by the pilot.

4. GENERAL REQUIREMENTS. In addition to the performance requirements set forth in the main text of this TSO, the following general requirements and equipment characteristics are defined below:

a. General Standards. The following general requirements must be met by all windshear warning and escape guidance systems:

(1) Airworthiness. Design and manufacture of the airborne equipment must provide for installation so as not to impair the airworthiness of the aircraft. Material must be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft systems. Workmanship must be consistent with high quality aircraft electromechanical and electronic component manufacturing practices.

(2) General Performance. The equipment must perform its intended function, as defined by the manufacturer.

(3) Fire Resistance. Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not significantly contribute to the propagation of fire, all materials used must be self-extinguishing. One means for showing compliance with this requirement is contained in 14 CFR Part 25, Appendix F.

(4) Operation of Controls. Controls intended for use during flight must be designed to minimize errors, and when operated in all possible combinations and sequences, must not result in a condition whose presence or continuation would be detrimental to the continued performance of the equipment.

(5) Accessibility of Controls. Controls that are not normally adjusted in flight must not be readily accessible to the operator.

(6) Interfaces. The interfaces with other aircraft equipment must be designed such that normal or abnormal windshear warning and escape guidance equipment operation must not adversely affect the operation of other equipment.

(7) Compatibility of Components. If a system component is individually acceptable but requires calibration adjustments or matching to other components in the aircraft for proper operation, it must be identified in a manner that will ensure performance to the requirements specified in this TSO.

(8) Interchangeability. System components which are identified with the same manufactured part number must be completely interchangeable.

(9) Control/Display Capability. A suitable interface must be provided to allow data input, data output, and control of equipment operation. The control/display must be operable by one person with the use of only one hand.

(10) Control/Display Readability. The equipment must be designed so that all displays and controls must be readable under all cockpit ambient light conditions ranging from total darkness to reflected sunlight and arranged to facilitate equipment usage. Limitations on equipment installations to ensure display readability should be included in the installation instructions.

(11) Effects of Test. The design of the equipment must be such that the application of the specified test procedures must not produce a condition detrimental to the performance of the equipment except as specifically allowed.

(12) Equipment Computational Response Time. The equipment must employ suitable update rates for computation and display of detection and guidance information.

(13) Supplemental Heating or Cooling. If supplemental heating or cooling is required by system components to ensure that the requirements of this TSO are met, they must be specified by the equipment manufacturer in the installation instructions.

(14) Self-Test Capability. The equipment must employ a self-test capability to verify proper system operation.

(i) Any manually initiated self-test mode of operation must automatically return the system to the normal operating mode upon completion of a successful test.

(ii) Any automatically activated self-test feature must annunciate this mode of operation to the pilot if this feature activates annunciation lights, aural messages, or displaces the guidance commands in any way.

(iii) Conduct of the system self-test feature must not adversely affect the performance of operation of other aircraft systems.

(iv) Failure of the system to successfully pass the self-test must be annunciated.

(15) Independence of Warning and Escape Guidance Functions. Irrespective of whether the warning and escape guidance functions are in a combined system or are separate systems, they should be sufficiently independent such that a failure of either system does not necessarily preclude or inhibit the presentation of information from the other. A warning system failure must not result in ambiguous or erroneous guidance system mode annunciation.

(16) System Reliability.

(i) The probability of a false warning being generated within the windshear warning system or the windshear warning and escape guidance system must be 1×10^{-4} or less per flight hour.

(ii) The probability of an unannunciated failure of the windshear warning system or the windshear warning and escape guidance system must be 1×10^{-5} or less per flight hour (1×10^{-3} or less per flight hour for systems installed in out-of-production aircraft as defined in 14 CFR § 121.358).

b. Equipment Functional Requirements - Standard Conditions. The equipment must meet the following functional requirements.

(1) Mode Annunciation. The windshear escape guidance display mode of operation must be annunciated to the pilot upon escape guidance activation during a windshear encounter and upon reversion to a different flight guidance mode.

(2) Malfunction/Failure Indications. The equipment must indicate:

(i) Inadequate or absence of primary power.

(ii) Equipment failures.

(iii) Inadequate or invalid warning or guidance displays or output signals.

(iv) Inadequate or invalid sensor signals or sources.

These malfunction/failure indications must occur independently of any operator action. The lack of adequate warning displays, escape guidance information, or sensor signals or sources must be annunciated when compliance with the requirements of this TSO cannot be assured.

(3) Windshear Caution Alert. If the equipment includes a windshear caution:

(i) It must provide an annunciation of increasing performance shear (updraft, increasing headwind, or decreasing tailwind) in accordance with the shear intensity curve shown in figure 1.

(ii) This caution alert must display or provide an appropriate output for display of an amber caution annunciation dedicated for this purpose. An aural alert may be provided as an option. The caution display (or output) should remain until the threshold windshear condition no longer exists (not less than 3 seconds) or a windshear warning alert occurs.

(iii) Gust conditions must not cause a nuisance caution alert. Turbulence must not cause more than one nuisance caution alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle) of system operation.

(4) Windshear Warning Alert.

(i) A windshear warning alert must provide an annunciation of decreasing performance shear (downdraft, decreasing headwind, or increasing tailwind) with a magnitude equal or greater than that shown in the shear intensity curve shown in Figure 1.

(ii) This warning alert must display or provide an appropriate output for display of a red warning annunciation labeled "windshear" dedicated for this purpose. The visual alert should remain at least until the threshold windshear condition no longer exists or for a minimum of 3 seconds, whichever is greater. An aural alert must be provided that annunciates "windshear" for three aural cycles. The aural alert need not be repeated for subsequent windshear warning alerts within the same mode of operation.

(iii) Gust conditions must not cause a nuisance warning alert. Turbulence must not cause more than one nuisance warning alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight) of system operation.

(5) Windshear Alert with Increased Approach Sensitivity and Reduced Takeoff Sensitivity Modes.

(i) Increased Approach Sensitivity Mode. If your system separates approach and takeoff scenarios, you may reduce the shear intensity level in the approach mode to increase the probability of providing timely windshear alerts. You may lower the floor of the shear intensity curve must alert curve in Figure 1 from 0.105 to 0.090. If you lower the floor, you may also modify the turbulence rejection tests in paragraph 4.d.(7).(ii) such that an alert in this region is not a failure of the turbulence rejection test.

(ii) Reduced Takeoff Sensitivity Mode. If your system separates approach and takeoff scenarios, you may desensitize the takeoff mode to reduce the probability of unwanted alerts. You may raise the floor of the shear intensity must alert curve in Figure 1 from 0.105 to 0.120.

(iii) Additional Reduced Takeoff Sensitivity Mode. Some high performance jet aircraft receive unwanted windshear alerts after takeoff when climbing at high rates through atmospheric wind gradients. If these unwanted alerts risk desensitizing pilots to windshear alerting, you may tailor the floor of the shear intensity must alert curve in Figure 1 to reduce these unwanted alerts under the following conditions:

(a) The airborne windshear warning and escape guidance system can determine the aircraft is in the takeoff versus approach phase.

(b) The aircraft is climbing at a high rate of climb, the aircraft continues to climb at a high rate, and the rate of climb is known to create unwanted windshear alerts.

(c) The aircraft power setting is at or near a level representative of the maximum for the segment of the takeoff, for example maximum takeoff thrust.

(d) The Figure 1 shear intensity must alert curve must be complied with after takeoff.

(6) Alerting Prioritization. Where alerting is prioritized in presentation for Windshear Warning and Escape Guidance System (Reactive Windshear), Forward Looking Windshear System, Terrain Awareness and Warning System, Ground Proximity Warning System, Traffic Collision Avoidance System, or where simultaneous aural annunciation could occur, sequencing must be implemented assuring reactive windshear warning alerts are presented or annunciated first. Reactive windshear alerts that are cautions have lower priority than all Terrain Awareness and Warning or Ground Proximity Warning System alerts.

(7) The reactive windshear systems caution alert should be disabled if a forward-looking windshear system is in operation. It is acceptable to issue reactive windshear caution alerts if the forward-looking windshear system is inoperative.

(8) Operating Altitude Range. The system must be designed to function from at least 50 feet above ground level (AGL) to at least 1000 feet AGL.

(9) Windshear Escape Guidance. Flight guidance algorithms must incorporate the following design considerations:

(i) At the point of system warning threshold, the available energy of the airplane must be properly managed through a representative number of wind field conditions. These conditions must take into account significant shear components in both the horizontal and vertical axes, individually and in combination.

(ii) The flight path guidance commands must be suitable to the dynamic response of aircraft of the type on which the system is intended for installation. You must demonstrate the flight guidance commands during a dynamic windshear encounter can be followed without resulting in pilot-induced oscillations.

(iii) If the magnitude of the shear components are such as to overcome the performance capability of the airplane, guidance commands must be such that ground impact will occur in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(iv) Flight guidance command information must be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available Head Up Display (HUD).

(v) Flight guidance displays which command flight path and pitch attitude should be limited to an angle-of-attack equivalent to onset of stall warning or maximum pitch command of 27º, whichever is less.

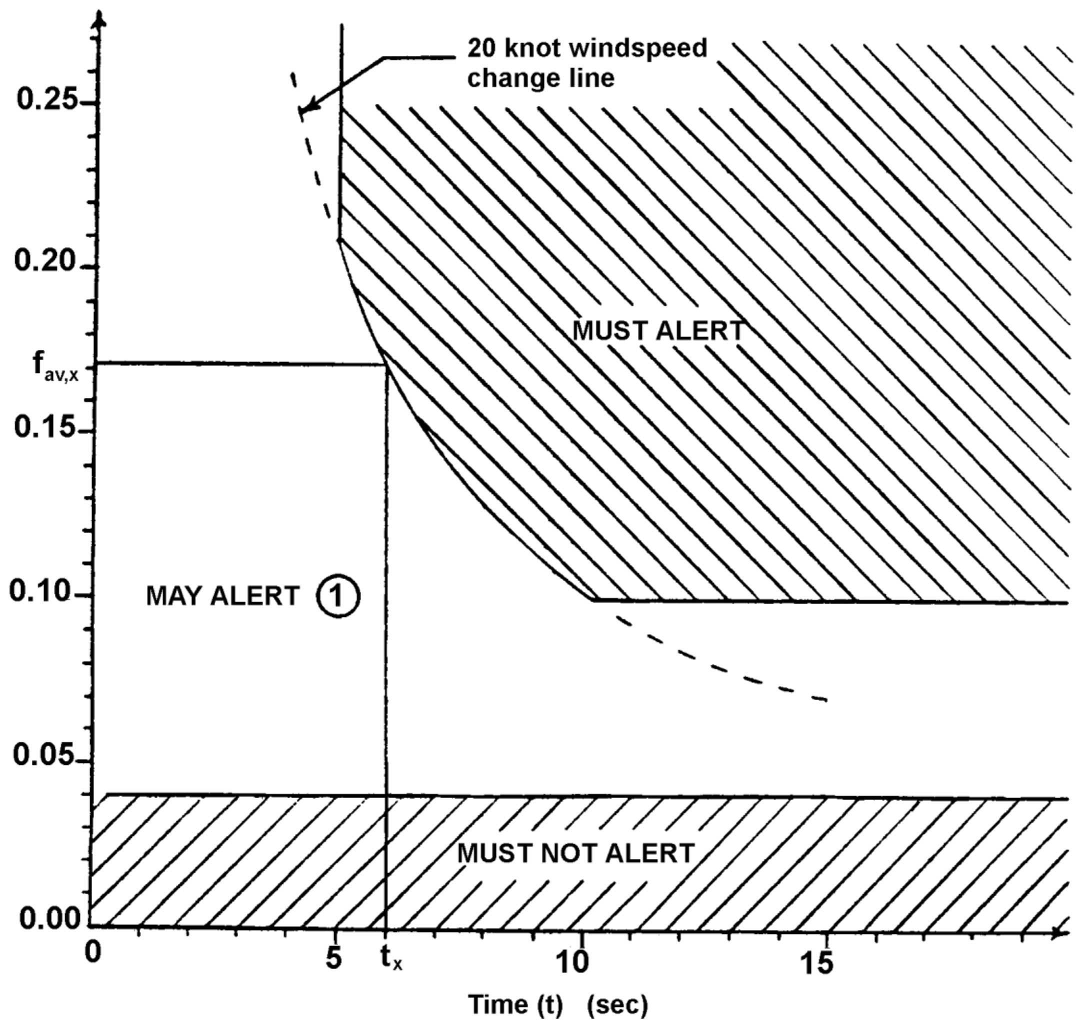
(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrent with or after the windshear warning alert occurs or may be manually selected. If manual selection is utilized, it must only be via the takeoff-go around (TOGA) switch or equivalent means (i.e., a function of throttle position, other engine parameters, etc.).

(vii) Manual deselection of windshear flight guidance and any auto recovery mode (if included) must be possible by means other than the TOGA switches.

(viii) Systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode should provide a smooth transition between modes. Flight guidance commands must not be removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

FIGURE 1.

SHEAR INTENSITY CURVE



$f_{av,x}$ = average shear intensity to cause a warning at time t_x (resulting in a 20 knot wind speed change, bounded as shown; applies to horizontal, vertical, and combination shear intensities)

$$= \frac{\int_{o}^{t_x} f(t)dt}{t_x}$$ whereby f(t) = instantaneous shear intensity at time t

① A nuisance warning test utilizing the Dryden turbulence model and discrete gust model are conducted independently from alert threshold tests to verify the acceptability of potential nuisance warnings due to turbulence or gusts.

c. Equipment Performance - Environmental Conditions.

(1) The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations. Table 1 defines the environmental tests required for the equipment. It shows the section numbers in DO-160G that describe the individual environmental tests. Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase "When Required" in Table 1. If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these "When Required" tests must be performed.

(2) Environmental Requirements. The following subset of performance requirements must be met under environmental conditions. Additionally, all system controls, displays, inputs, and outputs must perform their intended functions when subjected to the DO-160G environmental conditions.

(i) Section 4.(b)(1) - Mode Annunciation
(ii) Section 4.(b)(2) - Malfunction/Failure Indications
(iii) Section 4.(b)(3) - Windshear Caution Alert, except § 4.(b)(3)(iii)
(iv) Section 4.(b)(4) - Windshear Warning Alert, except § 4.(b)(4)(iii)
(v) Section 4.(b)(5) - Windshear Alert with Increased Approach Sensitivity and Reduced Takeoff Sensitivity Modes
(vi) Section 4.(b)(9) - Windshear Escape Guidance

Conduct environmental qualification test for the following shear intensity ($f_{av,x}$) and exposure time (sec) in figure 1: 0.1050, 10; 0.1748, 6; and 0.2100, 5. Ensure the system generates and displays alerts when required. You may use a single representative windshear waveform for all environmental tests, if your system design is such that different waveforms will not affect performance under environmental conditions. Gust and turbulence rejection tests are not required under environmental conditions.

Table 1

Required DO-160G Testing By Category

Environmental Test	DO-160G Section	Required Test
Temperature and Altitude	4	
Ground Survival Low Temperature and Short-Time Operating Low Temperature		√
Low Operating Temperature		√
Ground Survival High Temperature and Short-Time Operating High Temperature		√
High Operating Temperature		√
In-Flight Loss of Cooling		When Required
Altitude		√
Decompression		When Required
Overpressure		When Required
Temperature Variation	5	√
Humidity	6	√
Operational Shocks and Crash Safety	7	
Operational Shocks		√
Crash Safety		√
Vibration	8	√
Explosion proofness	9	When Required
Waterproofness	10	
Condensing Water Proof		When Required
Drip Proof		When Required
Spray Proof		When Required
Continuous Stream Proof		When Required
Fluids susceptibility	11	
Spray		When Required
Immersion		When Required
Sand and dust	12	When Required
Fungus resistance	13	When Required
Salt spray	14	When Required
Magnetic effect	15	√
Power input	16	
Normal Operating Conditions (ac and dc)		√
Abnormal Operating Conditions (ac and dc)		√
Load Equipment Influence on Aircraft Electrical Power System (ac and dc)		When Required

Table 1

Required DO-160G Testing By Category (Continued)

Environmental Test	DO-160G Section	Required Test
Voltage spike	17	
Category A Requirements (If Applicable)		√
Category B Requirements (If Applicable)		√
Audio frequency conducted susceptibility	18	√
Induced signal susceptibility	19	√
RF susceptibility	20	√
Emission of RF energy	21	√
Lightning induced transient susceptibility	22	√
Lightning Direct Effects	23	When Required
Icing	24	When Required
Electrostatic Discharge	25	When Required
Fire, Flammability	26	√

d. Equipment Test Procedures.

(1) Definitions of Terms and conditions of Tests. The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein:

(i) Power Input Voltage. Unless otherwise specified, all tests must be conducted with the power input voltage adjusted to design voltage ±2 percent. The input voltage must be measured at the input terminals of the equipment under test.

(ii) Power Input Frequency.

(a) In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g., 400 Hz), the input frequency must be adjusted to design frequency ±2 percent.

(b) In the case of equipment designed for operation from an AC power source of variable frequency (e.g., 300 to 1000 Hz), unless otherwise specified, the test must be conducted with the input frequency adjusted to within 5 percent of a selected frequency and within the range for which the equipment is designed.

(iii) Wind Field Models. Unless otherwise specified, the wind field models used for tests must be those specified in appendix **2** of this TSO.

(iv) Adjustment of Equipment. The circuits of the equipment under test must be aligned and adjusted in accordance with the manufacturer's recommended practices prior to the application of the specified tests.

(v) Test Instrument Precautions. Due precautions must be taken during the conduct of the tests to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedances of the equipment under test.

(vi) Ambient Conditions. Unless otherwise specified, all tests must be made within the following ambient conditions:

- Temperature: +15 to +35 degrees C (+59 to +95 degrees F).
- Relative Humidity: Not greater than 85%.
- Ambient Pressure: 84 - 107 kPa (equivalent to +5,000 to –1,500 ft.) (+1,525 to –460m).

(vii) Warm-up Period. Unless otherwise specified, all tests must be conducted after the manufacturer's specified warm-up period.

(viii) Connected Loads. Unless otherwise specified, all tests must be performed with the equipment connected to loads which have the impedance values for which it is designed.

(2) Test Procedures. The equipment must be tested in all modes of operation that allow different combinations of sensor inputs to show that it meets both functional and accuracy criteria.

Dynamic testing provides quantitative data regarding windshear warning and escape guidance equipment performance using a simplified simulation of flight conditions. This testing, when properly performed and documented, may serve to minimize the flight test requirements.

It must be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the windshear warning and escape guidance equipment, will produce performance commensurate with the requirements of this standard. Additional sensor inputs may be optionally provided to enhance equipment capability and/or performance.

The equipment required to perform these tests must be defined by the equipment manufacturer as a function of the specific sensor configuration of the equipment. Since these tests may be accomplished more than one way, alternative test equipment setups may be used where equivalent test function can be accomplished. Combinations of tests may be used wherever appropriate.

The test equipment signal sources must provide the appropriate signal format for input to the specific system under test without contributing to the error values being measured. Tests need only be done once unless otherwise indicated.

The scenarios established for testing windshear warning and escape guidance systems represent realistic operating environments to properly evaluate such systems. The wind field models contained in appendix **2** of this TSO should be used to evaluate the performance of the windshear warning and escape guidance system. The manufacturer may propose different wind field models provided it is shown that they represent conditions at least as severe as those contained in this TSO.

> **Note:** The test waveform parameters provided in the TSO are sufficiently broad to cover the wind field parameters observed in known accident cases. However, the manufacturer is encouraged to verify that the detection systems will actually detect these windshears by subjecting them to the wind field conditions specified for use in evaluating guidance commands.

(3) Test Setup. Simulator tests must be used to demonstrate the performance capability of the windshear warning and escape guidance equipment. A suitable equipment interface must be provided for recording relevant parameters necessary to evaluate the particular system under test. The aircraft simulator must be capable of appropriate dynamic modeling of a representative aircraft and of the wind field and turbulence conditions contained in appendices **2** and **3** of this TSO or other wind field/turbulence models found acceptable by the Administrator.

> **Note:** This section requires testing in a single representative aircraft simulator. Installation approval will require system testing in an aircraft simulator representative of the aircraft. Thus, we recommend you accomplish the section 4.d (3) simulator testing in as many representative simulators as necessary to cover all intended installations.

(4) Functional Performance (paragraphs (b)(1) through (b)(5), (b)(8), and (b)(9)). Each of the functional capabilities identified in paragraphs (b)(1) through (b)(5), (b)(7), and (b)(8) must be demonstrated with the windshear warning and escape guidance equipment powered. These capabilities must be evaluated either by inspection or in conjunction with the tests described in paragraphs (d)(5) through (d)(10).

(5) Mode Annunciation (paragraph (b)(1)). With the equipment operating, verify the windshear escape guidance display mode of operation is annunciated to the pilot upon escape guidance activation and upon reversion to a different flight guidance mode.

(6) Malfunction/Failure Indications (paragraph (b)(2)). Configure the equipment for simulation tests as defined in paragraph (d)(3).

(i) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), remove one at a time each required electrical power input to the equipment. There must be a failure indication by the equipment of each simulated failure condition.

(ii) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), cause each sensor or other signal input to become inadequate or invalid. There must be a failure indication by the equipment of each simulated failure condition.

(7) Windshear Caution Alert (paragraphs (b)(3) and (b)(5)(i)). For equipment incorporating a windshear caution alert function, accomplish the following tests:

(i) Configure the equipment for simulation test as defined in paragraph (d)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system must generate an appropriate caution alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Alert Within (sec) (3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.2
0.2100	5	5.7
0.2700 (2)	5	5

Notes:

(1) The average shear intensity which must result in a caution alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates must be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) In order to achieve the test condition with the shear intensity $f_{av,x}$ equal to or greater than 0.270, it is necessary to have an initial rise of sufficient rate to achieve a shear intensity f value that will allow subsequent rise and fall rates limited to 0.1 per second to achieve the required $f_{av,x}$ value.

(3) Account for latency due to the alert calculation and alert annunciation display functionality when measuring the alert time.

The test conditions specified above must be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for detection verification (9 conditions x 5 for each axis) for both performances increasing and decreasing windshears. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of an amber caution annunciation dedicated for this purpose. Verify the visual caution display (or output) remains at least until the threshold windshear condition no longer exists or a minimum of 3 seconds (whichever is greater), or until a windshear warning occurs.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix **4**. The system must be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix **4** for minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance caution must be generated during this test.

Alternative test equipment setup may be used to accomplish equivalent test function for the turbulence testing. Combination of analysis, simulation, and testing may be used to demonstrate the performance of the equipment.

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix **4**. No alert must be generated as a result of this test.

(8) Windshear Warning Alert (paragraphs (b)(4) and (b)(5)(ii)).

(i) Configure the equipment for simulation tests as defined in paragraph (d)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system must generate an appropriate warning alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Alert Within (sec) (3)
0.0200	20	no alert
0.0400	20	no alert
0.1050	10	10
0.1166	9	9
0.1311	8	8
0.1499	7	7
0.1748	6	6.6

0.2100	5	6.2
0.2700 (2)	5	5.7

Notes:

(1) The average shear intensity which must result in a warning alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates must be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) In order to achieve the test condition with the shear intensity $f_{av,x}$ equal to or greater than 0.270, it is necessary to have an initial rise of sufficient rate to achieve a shear intensity f value that will allow subsequent rise and fall rates limited to 0.1 per second to achieve the required $f_{av,x}$ value.

(3) Account for latency due to the alert calculation and alert annunciation display functionality when measuring the alert time.

The test conditions specified above must be repeated 5 times for each axis (horizontal and vertical). A total of 90 runs are required for detection verification (9 conditions x 5 for each axis) for both performances increasing and decreasing windshears. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify that the system displays or provides an appropriate output for display of a red warning annunciation labeled "windshear" dedicated for this purpose. Verify that the visual warning display (or output) remains until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. Verify that an aural alert is provided that annunciates "windshear" for three aural cycles.

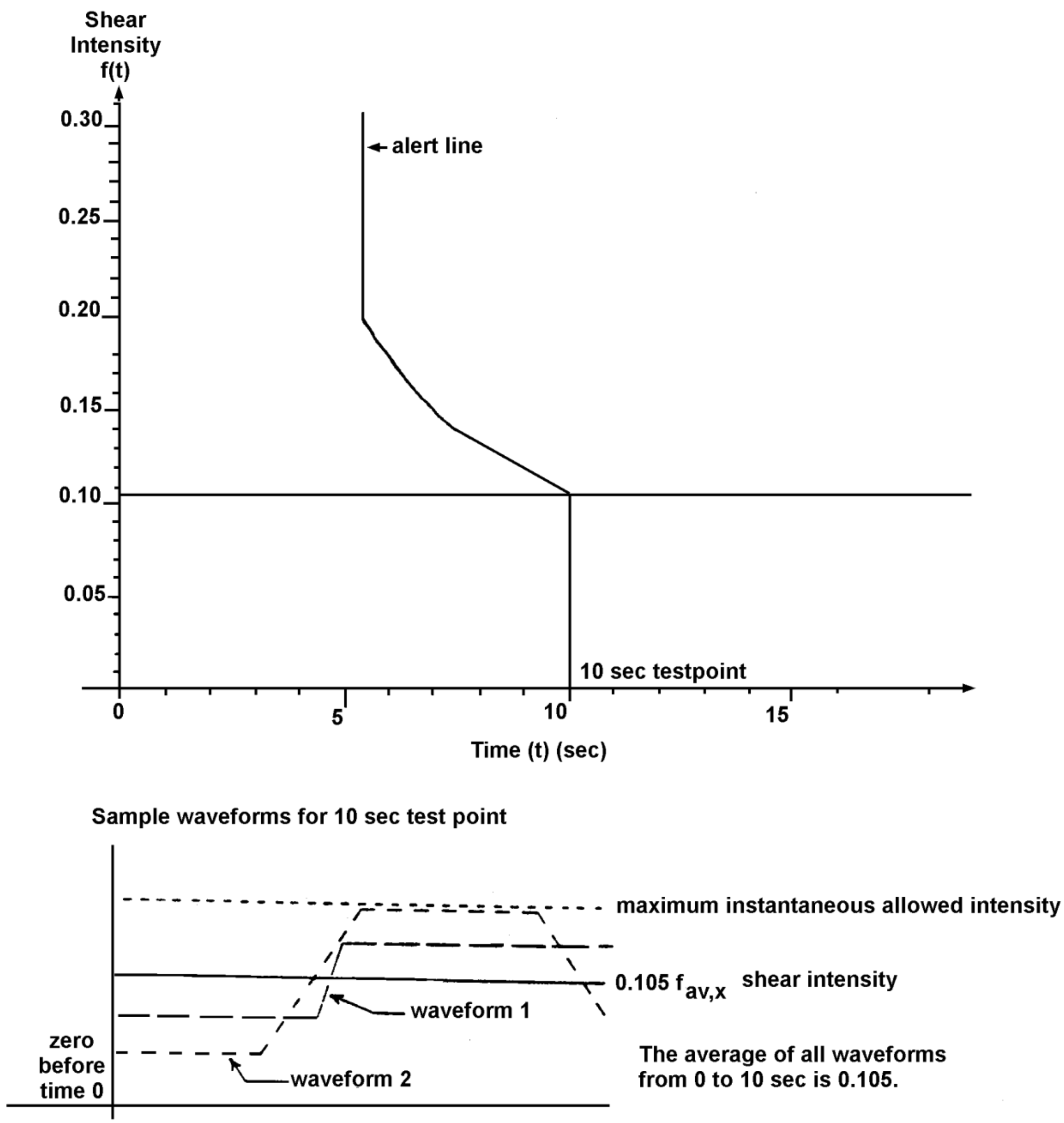
(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix **4**. The system must be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix **4** for minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance warning must be generated during this test.

An alternative test equipment setup may be used to accomplish equivalent test function for the turbulence testing. A combination of analysis, simulation, and testing may be used to demonstrate the performance of the equipment specified in this paragraph 4.d(8)(ii).

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix **4**. No alert must be generated as a result of this test.

FIGURE 2.

WINDSHEAR ALERT TEST



(9) Operating Altitude Range (paragraph (b)(8)). Configure the equipment for simulation tests as defined in paragraph (d)(3). Simulate a takeoff to an altitude of at least 1500 feet AGL. Verify the windshear warning and escape guidance system is operational from at least 50 feet AGL to at least 1000 feet AGL. Simulate an approach to landing from 1500 feet AGL to touchdown. Verify the windshear warning and escape guidance system is operational from at least 1000 feet AGL to at least 50 feet AGL.

(10) Windshear Escape Guidance (paragraph (b)(9)). Configure the equipment for simulation tests as defined in paragraph (d)(3). Subject the equipment to each of the wind field conditions contained in appendix **2** for each operating mode (takeoff, approach, landing, etc.) available. Each test condition must be repeated 5 times. Recovery actions for the fixed pitch method comparison must be initiated immediately upon entering the shear condition.

Notes:

(1) Evaluate windshear escape guidance commands using a simulation that incorporates necessary dynamic modeling of representative aircraft (more than 1 representative aircraft model may be necessary) in which installation is intended. Dynamic modeling of the representative aircraft should include consideration of all relevant effects, including, but not limited to, pitch and roll rates, control authority, delays between control inputs and aircraft responses, display system lead and lag, etc.

(2) The simulator should provide for a pilot in the loop evaluation of guidance flyability during simulated windshear encounters. Guidance command gains should be consistent with those incorporated in the flight guidance system. While “fine tuning” of guidance commands to obtain optimum performance for specific airplane may be accomplished, use of unique tailoring for specific airplane may not be necessary. Evaluation through means of a suitable engineering simulation may be acceptable to demonstrate suitability of guidance commands for a representative airplane. However, the equipment manufacturer should demonstrate that the flight guidance commands during a dynamic windshear encounter can be followed without resulting in pilot-induced oscillations.

(i) Verify the flight path guidance commands manage the available energy of the aircraft to achieve the desired trajectory through the shear encounter. These tests must be performed with vertical only, horizontal only, and combination vertical and horizontal shear conditions. You may reduce the number of times you repeat each of these tests conditions below five. To reduce the number of repetitions below five you must have gathered sufficient data to demonstrate the flight path guidance commands meet these requirements. You should also include aircraft weight and center of gravity variations if applicable.

(a) For the takeoff case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(b) For the approach/landing case, verify that the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing maximum available thrust and a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(c) For shear conditions exceeding the available performance capability of the aircraft, verify the flight guidance commands result in ground impact in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

> **Note:** There is no requirement to perform the tests described in §§ 4(d)(10)(ii) through (vii) with horizontal only, vertical only, and combination vertical and horizontal shear conditions. You may perform the tests described in §§ 4(d)(10)(ii) through (vii) with only the combination vertical and horizontal shear conditions.

(ii) Verify that the flight guidance command outputs are capable of display on associated flight displays. Interface specifications must be verified and determined to be appropriate for the systems identified in the equipment installation instructions.

(iii) Verify that pitch attitude commands do not result in an angle-of- attack exceeding the onset of stall warning or a maximum pitch command of 27°, whichever is less.

(iv) For systems incorporating manual activation of recovery flight guidance commands, verify the system is activated only by the TOGA switches (or equivalent means). For systems providing automatic activation of recovery guidance, verify the system is activated concurrent with the windshear warning alert.

(v) Verify that windshear recovery guidance commands and any automatic recovery mode can be deselected by a means other than the TOGA switches.

(vi) For systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode, verify that the transition between flight guidance modes provides smooth guidance information.

(vii) Verify that flight guidance commands are not removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above 1.3 V_{s1} for at least 30 seconds.

APPENDIX 2

This appendix contains data that defines the wind field models to be used in conducting the tests specified in paragraph 4(d)(10) of appendix **1** of this TSO. This material was developed by the National Aeronautics and Space Administration (NASA), reference NASA Technical Memorandum 100632 [ref. 1].

The downburst model parameters below provide the variables to be used to obtain the representative test conditions: (1)(2)

Radius of Downdraft (ft)	Maximum Outflow (ft/s)	Altitude of Max. Outflow (ft)	Distance From Starting Point (3) (ft)
920	37	98	20000 (-9000)
1180	47.6	98	15000 (-14000)
2070	58.4	131	25000 (-4000)
4430	68.9	164	30000 (1000)
9010	72.2	262	30000 (1000)
3450	88.2	197	25000 (-4000)
3180	53.1	262	30000 (1000)
1640	46	164	25000 (-4000)
5250	81.3	197	30000 (1000)
1250	67.6	100	25000 (-4000)

(1) From analytic microburst model documented in NASA TM-100632. These parameters are based on data from Proctor's Terminal Area Simulation System (TASS) model.

(2) For the takeoff case, the downburst center is positioned at the point the aircraft lifts off the runway for all test cases.

(3) For the approach/landing case, the downburst center is positioned as stated. The test is begun with the aircraft at an initial altitude of 1500 feet on a 3° glideslope (touchdown point approximately 29000 feet away). Distance from starting point indicates where the center of the downburst shaft is located relative to the starting point. The number in parenthesis next to it indicates the relative distance of the microburst center from the touchdown point (not the end of the runway). A negative number indicates that the microburst center is located before the touchdown point, positive indicates it is past the touchdown point.

SUMMARY

A simple downburst model has been developed for use in batch and real-time piloted simulation studies of guidance strategies for terminal area transport aircraft operations in wind shear conditions. The model represents an axisymmetric stagnation point flow, based on velocity profiles from the TASS model developed by Proctor [ref. 6-9] and satisfies the mass continuity equation in cylindrical coordinates. Altitude dependence, including boundary layer effects near the ground, closely matches real-world measurements, as do the increase, peak, and decay of outflow and downflow with increasing distance form the downburst center. Equations for horizontal and vertical winds were derived, and found to be infinitely differentiable, with no singular points existent in the flow field. In addition, a simple relationship exists among the ratio of maximum horizontal to vertical velocities, the down draft radius, depth of outflow, and altitude of maximum outflow. In use, a microburst can be modeled by specifying four characteristic parameters. Velocity components in the x, y, and z directions, and the corresponding nine partial derivatives are obtained easily from the velocity equations.

INTRODUCTION

Terminal area operation of transport aircraft in a windshear environment has been recognized as a serious problem. Studies of aircraft trajectories through downbursts show that specific guidance strategies are needed for aircraft to survive inadvertent downburst encounters. In order for guidance strategies to perform in simulations as in actual encounters, a realistic set of conditions must be present during development of the strategies. Thus, airplane and wind models that closely simulate real-world conditions are essential in obtaining useful information from the studies.

Wind models for use on personal computers or for simulators have been difficult to obtain because variability of downburst characteristics makes analytical models unrealistic.

Bray [ref. 2] developed a method for analytic modeling of windshear conditions in flight simulators, and applied his method in modeling a multiple downburst scenario from Joint Airport Weather Studies (JAWS) data. However, the altitude dependence of his model is not consistent with observed data, and, although flexibility in sizing the downbursts is built into the model, it does not maintain the physical relationships which are seen in real-world data among the sizing parameters. In particular, boundary layer effects should cause radial velocity to decay vertically to zero at the ground, as does the vertical velocity.

In a study conducted at NASA Langley Research Center, three different guidance strategies for a Boeing 737-100 airplane encountering a microburst on takeoff were developed [ref. 3-4]. These strategies were first developed using a personal computer, and then implemented in a pilot-in-the-loop simulation using a very simple wind model in both efforts [fig. 1]. This model consisted of a constant outflow outside of the downburst radius and a constant slope headwind to tailwind shear across the diameter of the downburst. It was recognized that a more realistic wind model could significantly alter the outcome of the trajectory. For the subsequent part of this study, which involves altering the airplane model to simulate approach to landing and escape maneuvers and additional takeoff cases, a more realistic wind model was preferred. The simple analytical model outlined in this report was developed for this purpose.

SYMBOLS

JAWS	Joint Airport Weather Studies
NIMROD	Northern Illinois Meteorological Research on Downbursts
R	radius of downburst shaft (ft)
r	radial coordinate (distance from downburst center) (ft)
TASS	Terminal Area Simulation System
u	velocity in r-direction (or x-direction) (kts)
v	velocity in y-direction (kts)
w	velocity in z-direction (kts)
w_{max}	magnitude of maximum vertical velocity (kts)
u_{max}	magnitude of maximum horizontal velocity (kts)
x	horizontal (runway) distance, airplane to downburst center (ft)
y	horizontal (side) distance, airplane to downburst center (ft)
z	airplane altitude above ground level (ft)
z_h	depth of outflow (ft)
z_m	height of maximum U-velocity (ft)
z_{m2}	height of half maximum U-velocity (ft)
z*	characteristic height, out of boundary layer (ft)
ϵ	characteristic height, in boundary layer (ft)
λ	scaling factor (s^{-1})

DEVELOPMENT OF VELOCITY EQUATIONS

Beginning with the full set of Euler and mass continuity equations, some simplifying assumptions about the down burst flow conditions were made. Effects of viscosity were parameterized explicitly, and the flow was assumed to be invariant with time. The downburst is axisymmetric in cylindrical coordinates, and characterized by a stagnation point at the ground along the axis of the downflow column. The flow is incompressible, with no external forces or moments acting on it.

The resulting mass conservation equation is

$$\nabla \cdot v = 0. \tag{1}$$

Written out in full, equation 2 is

$$\frac{\partial u}{\partial r} + \frac{\partial w}{\partial z} + \frac{u}{r} = 0. \tag{2}$$

This equation is satisfied by solutions of the form

$$w = g\left(r^2\right)q\left(z\right) \tag{3a}$$

$$u = \frac{f\left(r^2\right)}{r}p\left(z\right) \tag{3b}$$

provided that

$$f'\left(r^2\right) = \frac{\lambda}{2}g\left(r^2\right) \tag{4a}$$

$$q'\left(z\right) = -\lambda p\left(z\right). \tag{4b}$$

Note that $f'\left(r^2\right) = \frac{\partial f\left(r^2\right)}{\partial r^2}$. To solve this system of equations, solutions were assumed for two of the functions and the other two were obtained from equations 4a and 4b.

It was desired that the velocity profiles of this analytic model exhibit the altitude and radial dependence shown in the large-scale numerical weather model TASS (Terminal Area Simulation System) [ref. 6-9]. The TASS model is based on data from the Joint Airport Weather Studies (JAWS) [ref. 10], and provides a three-dimensional velocity field, frozen in time, for given locations of an airplane within the shear [ref. 11-12]. Figure 2 of Appendix 3 shows dimensionless vertical profiles of horizontal velocity, u, for TASS data, laboratory data obtained by impingement of a jet on a flat plate, and data from NIMROD (Northern Illinois Meteorological Research on Downbursts) [ref. 13-21]. Specific points of interest are the maximum horizontal velocity (located 100 - 200 meters above the ground), below which is a decay region due to boundary layer effects, zero velocity at the stagnation point on the ground, and an exponential decay with altitude above the maximum velocity altitude. Vertical velocity profiles from TASS data are shown in figure 3 of Appendix 3, also exhibiting a decay to zero at the stagnation point.

The radially varying characteristics desired for the horizontal wind were two peaks of equal magnitude and opposite direction located at a given radius, with a smooth, nearly linear transition between the two. Beyond the peaks, the velocity should show an exponential decay to zero. The vertical velocity was required to have a peak along the axis of symmetry (r = 0), and decay exponentially at increasing radius.

A pair of shaping functions that gave velocity profiles matching TASS data as required is given below.

$$g(r^2) = e^{-(r/R)^2}$$

$$p(z) = e^{-z/z*} - e^{-z/\varepsilon}$$

The remaining solutions were found by integrating equations 4a and 4b, yielding:

$$f\left(r^2\right) = \frac{\lambda R^2}{2}\left[1 - e^{-(r/R)^2}\right]$$

$$q(z) = -\lambda\left\{\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z*\left(e^{-z/z*} - 1\right)\right\}.$$

Figures 4 and 5 of Appendix 3 show plots of these shaping functions.

Combining the functions as in equation 3, the horizontal and vertical velocities are expressed as

$$u = \frac{\lambda R^2}{2r}\left[1 - e^{-(r/R)^2}\right]\left(e^{-z/z*} - e^{-z/\varepsilon}\right) \tag{5}$$

$$w = -\lambda e^{-(r/R)^2}\left[\varepsilon\left(e^{-z/\varepsilon} - 1\right) - z*\left(e^{-z/z*} - 1\right)\right]. \tag{6}$$

By taking derivatives of equations 5 and 6 with respect to r and z, respectively, and substituting in equation 2, it can be shown that the velocity distributions satisfy continuity.

The parameters z* and ε were defined as characteristic scale lengths associated with "out of boundary layer" and "in boundary layer" behavior, respectively. Analysis of TASS data indicated that $z* = z_{m2}$, the altitude at which the magnitude of the horizontal velocity is half the maximum value.

It was also noted that the ratio

$$\frac{z_m}{z^*} = 0.22$$

To determine the location of the maximum horizontal velocity, the partial derivatives of u with respect to r and z where set equal to zero. The resulting equation for the r− derivative is

$$2\left(\frac{r}{R}\right)^2 = e^{-(r/R)^2} - 1.$$

The resulting equation for the z-derivative is

$$\frac{z_m}{z*} = \frac{1}{(z*/\varepsilon) - 1}\ln(z*/\varepsilon).$$

Recalling that zm/z* = 0.22, the values 1.1212 and 12.5 were obtained from iteration for the ratios r/R and z*/ε, respectively.

Using these values, the maximum horizontal velocity can be expressed as $u_{max} = 0.2357\ \lambda\ R$. The maximum vertical wind is located at r = 0 and $z = z_h$, by definition, and is given by $w_{max} = \lambda z*\left(e^{-\left(z_h/z*\right)} - 0.92\right)$.

A ratio of maximum outflow and downflow velocities can be formed

$$\frac{u_m}{w_m} = \frac{0.2357R}{z*\left(e^{-\left(z_h/z*\right)} - 0.92\right)}.$$

The Scaling factor, λ, was determined by using either of equations 5 or 6 for horizontal or vertical velocity, and setting it equal to the maximum velocity, u_{max} or w_{max}, respectively. Solving for λ resulting in:

$$\lambda = \frac{w_m}{z*\left(e^{-\left(z_h/z*\right)} - 0.92\right)} = \frac{u_m}{0.2357R.}$$

The velocity equations were easily converted to rectangular coordinates, as shown in this Appendix **3**. Partial derivatives with respect to x, y, and z were obtained by differentiating the velocity equations, and are also listed in this Appendix **2**.

DISCUSSION AND RESULTS

Vertical and horizontal velocity profiles for u and w are shown in figures 6 and 7 of Appendix 3. Four profiles are shown for each component. The horizontal wind profiles in figure 6 of Appendix 3 were taken at the radios of peak outflow (r = 1.1212 R) and at about one-fourth that radius (r = 0.3 R), where the maximum outflow is approximately half the value at the peak outflow radius. The vertical wind profiles were taken at the radius of peak downflow (r = 0) and at r = 0.3 R. Horizontal wind and vertical wind profiles in figure 7 of Appendix 3 were taken at altitudes of $h = z_m$ (maximum outflow), h = z* (half-maximum outflow), and $h = z_h$ (depth of outflow).

This analytical model is compared with TASS, laboratory, and NIMROD data in figure 8 of Appendix 3. The figure shows that, when nondimensionalized by the altitude of half-maximum outflow (z*) and by the maximum outflow ($u = u_{max}$), the analytical model agrees closely with the other data.

Different shears can be modeled by specifying four parameters, and the location of downburst center relative to the airplane flying through it. The four parameters are: 1) a characteristic horizontal dimension; 2) maximum wind velocity; 3) altitude of maximum outflow; and 4) depth of outflow. The characteristic horizontal dimension specified is the radius of the downdraft column, noting that this is about 89 percent of the radius of peak outflow. The maximum wind velocity can be either horizontal or vertical.

CONCLUDING REMARKS

The analytic microburst model developed for use in real-time and batch simulation studies was shown to agree well with real-world measurements for the cases studied. The functions chosen for the model showed boundary-layer effects near the ground, as well as the peak and decay of outflow at increasing altitudes, and increasing downflow with altitude. The exponential increase and decay of downflow and outflow (in the radial direction) are also characterized by the model. Equations for horizontal and vertical winds are simple and continuously differentiable, and partial derivatives in rectangular or cylindrical coordinates can be easily obtained by direct differentiation of the velocity equations. The governing equation for this system is the mass conservation law, and the analytic velocity functions developed here satisfied this condition. The model is sustained by a strong physical basis and yields high fidelity results, within the limitations of maintaining simplicity in the model, and variability of the microburst phenomenon. Parameterization of some of the characteristic dimensions allows flexibility in selecting the size and intensity of the microburst.

REFERENCES

1. A Simple, Analytic 3-Dimensional Downburst Model Based on Boundary Layer Stagnation Flow, Rosa M. Oseguera and Roland L. Bowles, July 1988.

2. Bray, R. S.: Application of Data to Piloted Simulations. Wind Shear/Turbulence Inputs To Flight Simulation and Systems Certification, NASA CP-2474, 1987, pp. 97-115.

3. Hinton, D. A.: Aircraft Trajectory Guidance During Wind Shear Encounters. Master's Thesis, George Washington University, January 1988.

4. Hinton, D.A.: Flight management strategies for escape from microburst encounters, NASA TR 4057, 29 pp, 1988.

5. Hinton, D.A.: Relative merits of reactive and forward-look detection for wind shear encounters during landing approach for various microburst escape strategies, NASA TM-4158, DOT/FAA/DS-89/35, 1990.

6. Proctor, F.H.: The Terminal Area Simulation System, Volume I: Theoretical Formulation, NASA Contractor Report 4046, April 1987.

7. Proctor, F. H., 1988: Numerical simulations of an isolated microburst. Part I: Dynamics and structure, J. Atmos. Sci., 45, pp. 3137-3160.

8. Proctor, F.H.: The Terminal Area Simulation System, Volume II: Verification Cases, NASA Contractor Report 4047, April 1987.

9. Proctor, F. H., 1989: Numerical simulations of an isolated microburst. Part II: Sensitivity experiments, J. Atmos. Sci., 46, pp. 2143-2165.

10. Frost, W.: Modeling and Implementation of Wind Shear Data. Wind Shear/ Turbulence Inputs to Flight Simulation and Systems Verification, NASA CP-2474, 1987, pp. 49-66.

11. Proctor, F. H.: NASA Wind Shear Model – Summary of Model Analysis. Airborne Wind Shear Detection and Warning Systems, NASA CP-10006, 1988, pp. 29-66.

12. Proctor, F. H., and Bowles, R. L.: Three-dimensional simulation of the Denver 11 July 1988 microburst-producing storm, Meteorol. and Atmos. Phys., 49, 1992, pp. 107-124.

13. Fujita, T. T.: Tornadoes and Downbursts in the Context of Generalized Planetary Scales, Journal of Atmospheric Sciences, vol. 38, no. 8, August 1981, pp. 1511-1534.

14. Oseguera, R. M.; Bowles, R. L.; and Robinson, P. A., 1992: Airborne In Situ Computation of the Wind Shear Hazard Index, AIAA Paper 92-0291, 1992.

15. Lewis M. S., Robinson P. A., Hinton D. A., Bowles R. L.: The relationship of an integral wind shear hazard to aircraft performance limitations, NASA TM-109080, 1994.

16. Arbuckle, P. D., Lewis M. S., Hinton D. A.: Airborne systems technology application to the windshear threat, 20th Congress of the International Council of the Aeronautical Sciences, ICAS Paper No. 96-5.7.1, pp. 1640-1650, 1996.

17. Airborne Windshear Detection and Warning Systems. First Combined Manufacturers' and Technologists' Conference, NASA CP-10006, DOT/FAA/PS-88/7, 1988.

18. Airborne Windshear Detection and Warning Systems, Second Combined Manufacturers' and Technologists' Conference, NASA CP-10050, 1990.

19. Airborne Windshear Detection and Warning Systems, Third Combined Manufacturers' and Technologists' Conference, NASA CP-10060, DOT/FAA/RD-91/2-1, 1991.

20. Airborne Windshear Detection and Warning Systems, Fourth Combined Manufacturers' and Technologists' Conference, NASA CP-10105, DOT/FAA/RD-92/19-1, 1992.

21. Airborne Windshear Detection and Warning Systems, Fifth and Final Combined Manufacturers' and Technologists' Conference, NASA CP-10139, DOT/FAA/RD-94/14-1, 1994.

APPENDIX 3

This Appendix describes the conversion of the velocity equations in Appendix 2 to rectangular coordinates.

Define intermediate variables to simplify written equations:

$e_r = e^{-(r/R)^2}$

$e_e = e^{-(h/\varepsilon)}$

$e_z = e^{-(h/z^*)}$

$e_d = e_z - e_e$

$e_c = z^*(1 - e_z) - \varepsilon(1 - e_e)$

Horizontal and Vertical Velocities

$$W_X = \frac{\lambda R^2}{2r^2}(1 - e_r)e_d x_{ad}$$

$$W_y = \frac{\lambda R^2}{2r^2}(1 - e_r)e_d y_{ad}$$

$$W_h = -\lambda e_r e_c$$

Partial Derivatives

$$\frac{\partial w_x}{\partial x} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2x_{ad}^2}{R^2} + \frac{2x_{ad}^2}{r^2} - 1\right) - \frac{2x_{ad}^2}{r^2} + 1\right]$$

$$\frac{\partial w_x}{\partial y} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_x}{\partial h} = \frac{\lambda R^2 x_{ad}}{2r^2}(1 - e_r)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_y}{\partial x} = \frac{\lambda R^2 x_{ad} y_{ad} e_d}{r^2}\left[e_r\left(\frac{1}{R^2} + \frac{1}{r^2}\right) - \frac{1}{r^2}\right]$$

$$\frac{\partial w_y}{\partial y} = \frac{\lambda R^2 e_d}{2r^2}\left[e_r\left(\frac{2y_{ad}^2}{R^2} + \frac{2y_{ad}^2}{r^2} - 1\right) - \frac{2y_{ad}^2}{r^2} + 1\right]$$

$$\frac{\partial w_y}{\partial h} = \frac{\lambda R^2 y_{ad}}{2r^2}(1 - e_r)\left[\frac{e_e}{\varepsilon} - \frac{e_z}{z^*}\right]$$

$$\frac{\partial w_h}{\partial x} = \frac{2\lambda x_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial y} = \frac{2\lambda y_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial h} = -\lambda e_r e_d$$

$$\frac{\partial w_h}{\partial y} = \frac{2\lambda y_{ad} e_r e_c}{R^2}$$

$$\frac{\partial w_h}{\partial h} = -\lambda e_r e_d$$

Other Relationships

From TASS $\qquad \dfrac{z_m}{z^*} = 0.22 \qquad \dfrac{z^*}{\varepsilon} = 12.5$

Maximums

$$w_{x\,max} = 0.2357\lambda R$$

$$w_{y\,max} = w_{x\,max}$$

$$w_{h\,max} = \lambda z^*(e^{-(z_h/z^*)} - 0.92)\ .$$

(λ is determined from the above relationships)

$$\frac{w_{x_{max}}}{w_{h_{max}}} = \frac{0.2357R}{z^*\left(e^{-z_h/z^*} - 0.92\right)}$$

Variable List

z^* = altitude where w_x is half the value of $w_{x\,max}$ (ft)
ε = characteristic height of boundary layer effects (ft)
z_h = depth of outflow (ft)
z_m = altitude of maximum outflow (ft)
λ = scaling parameter (s^{-1})
r = radial distance from airplane to downburst (ft)
h = altitude of airplane (ft)
R = radius of downdraft (ft)
x_{ad}, y_{ad} = x, y coordinates, airplane to microburst (ft)
$w_{x\,max}$, $w_{y\,max}$, $w_{h\,max}$ maximum winds, x, y, and h directions

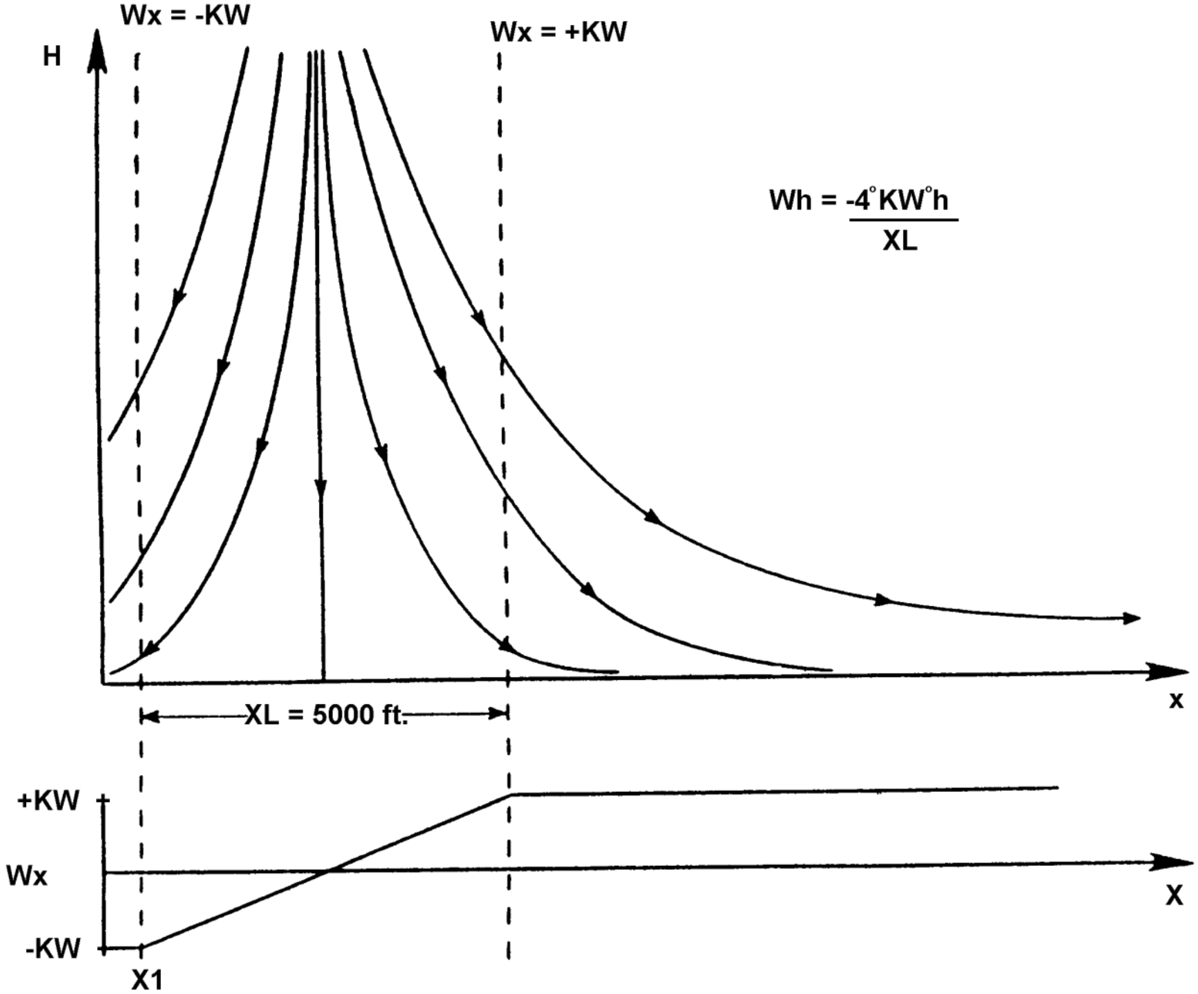


Figure 1. Wind Model Used In Guidance Studies

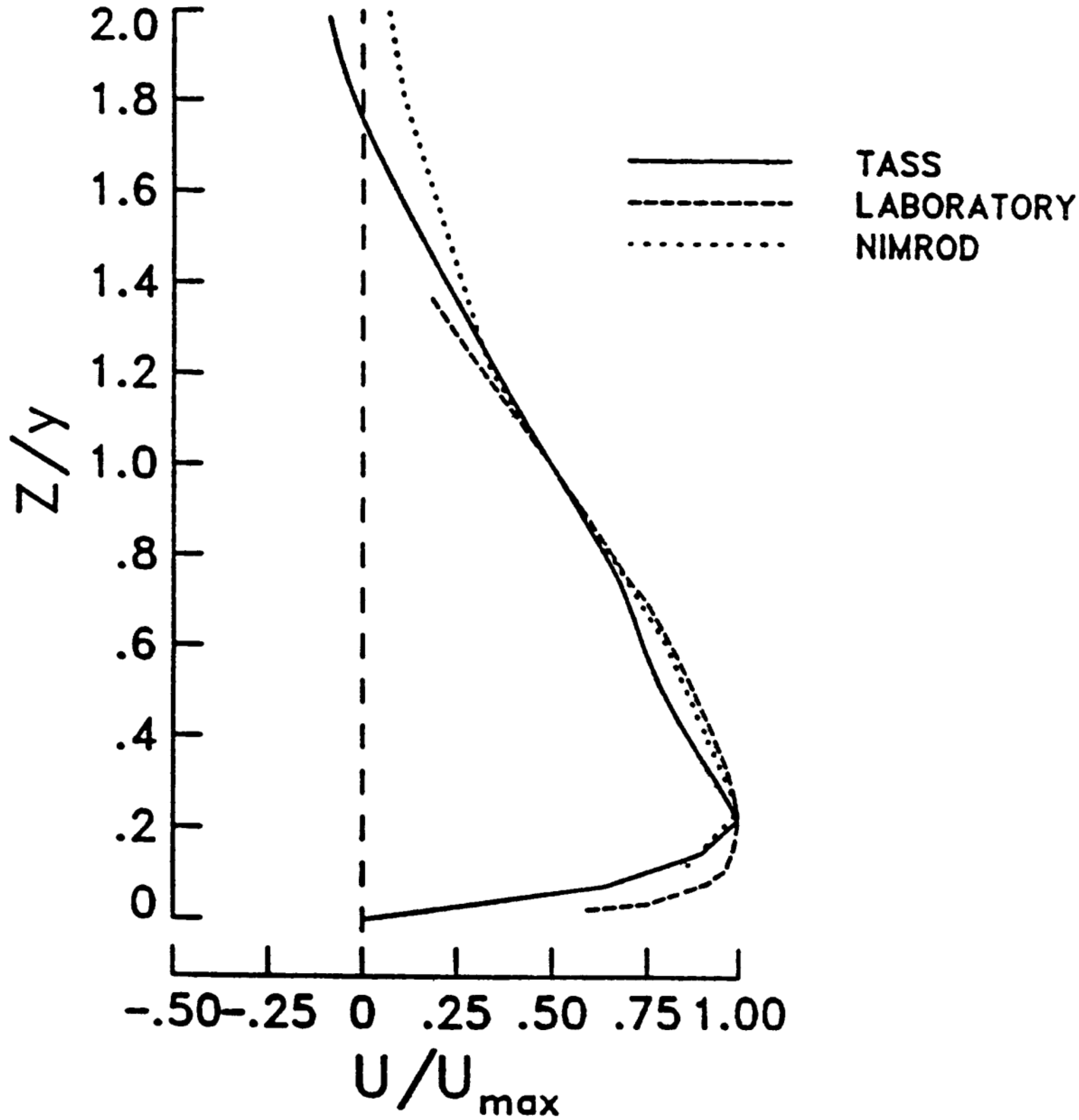


Figure 2. Vertical Profile of Microburst Outflow (Nondimensional)

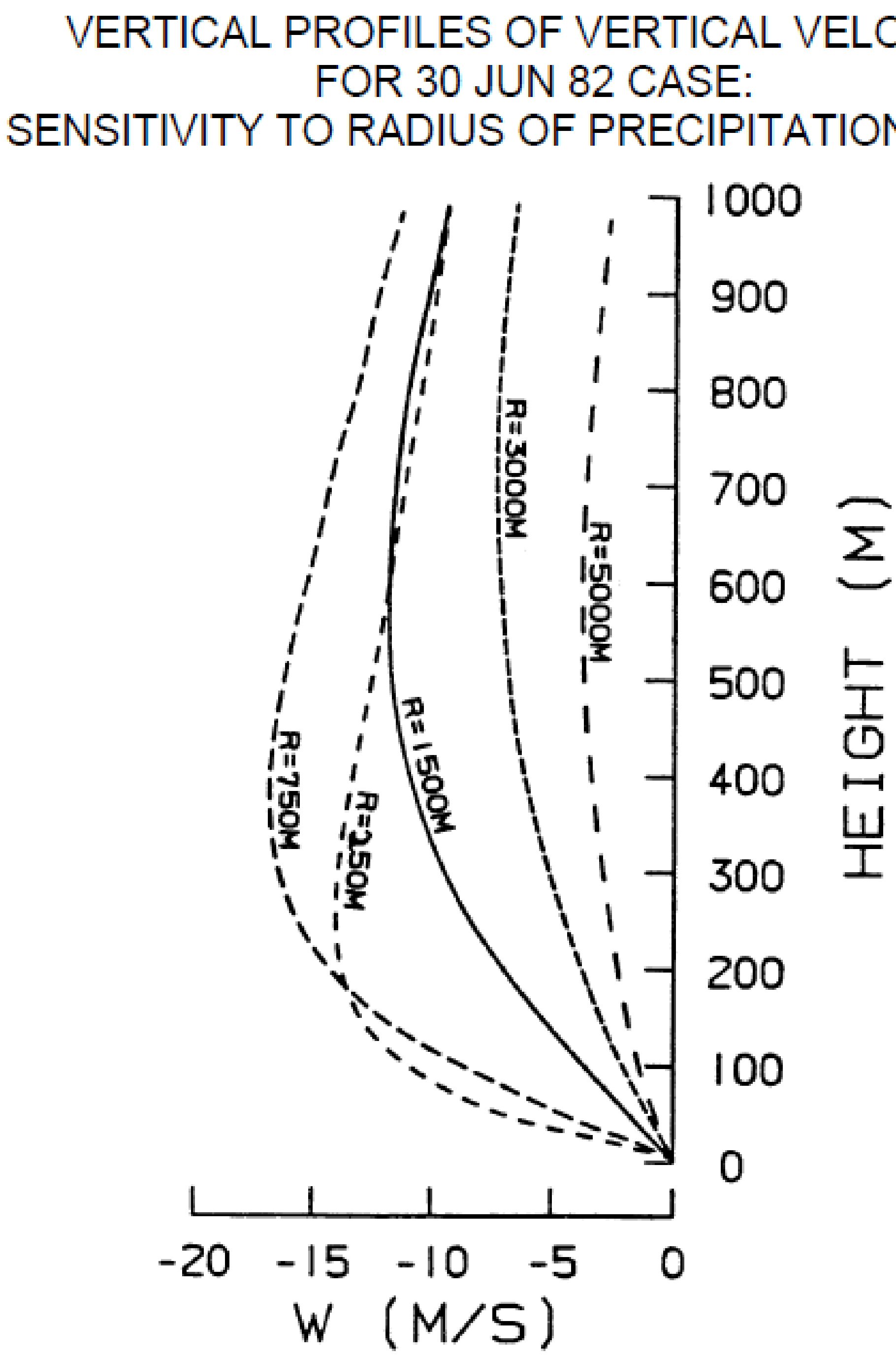


Figure 3. Vertical Profile of Microburst Downflow

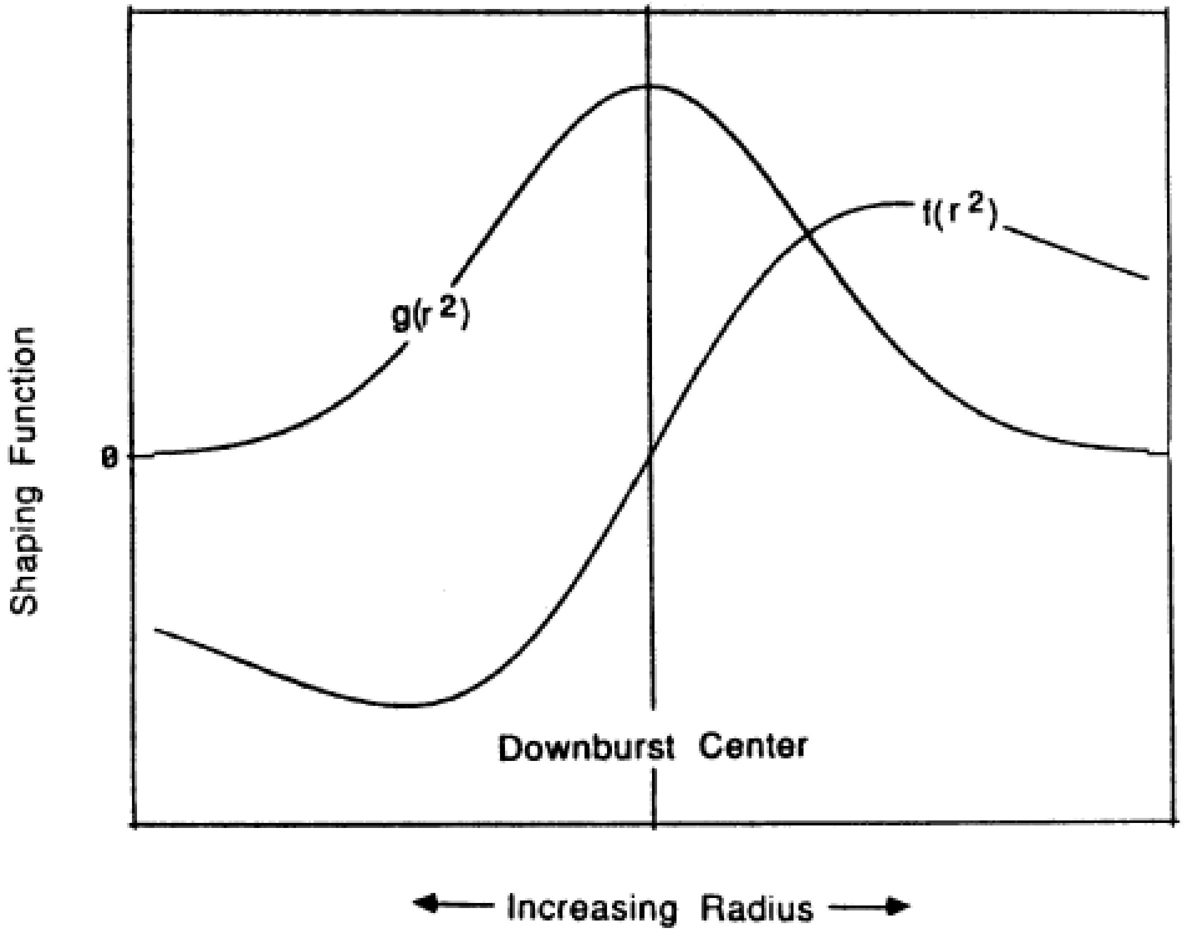


Figure 4. Characteristic Variation of Horizontal Shaping Functions

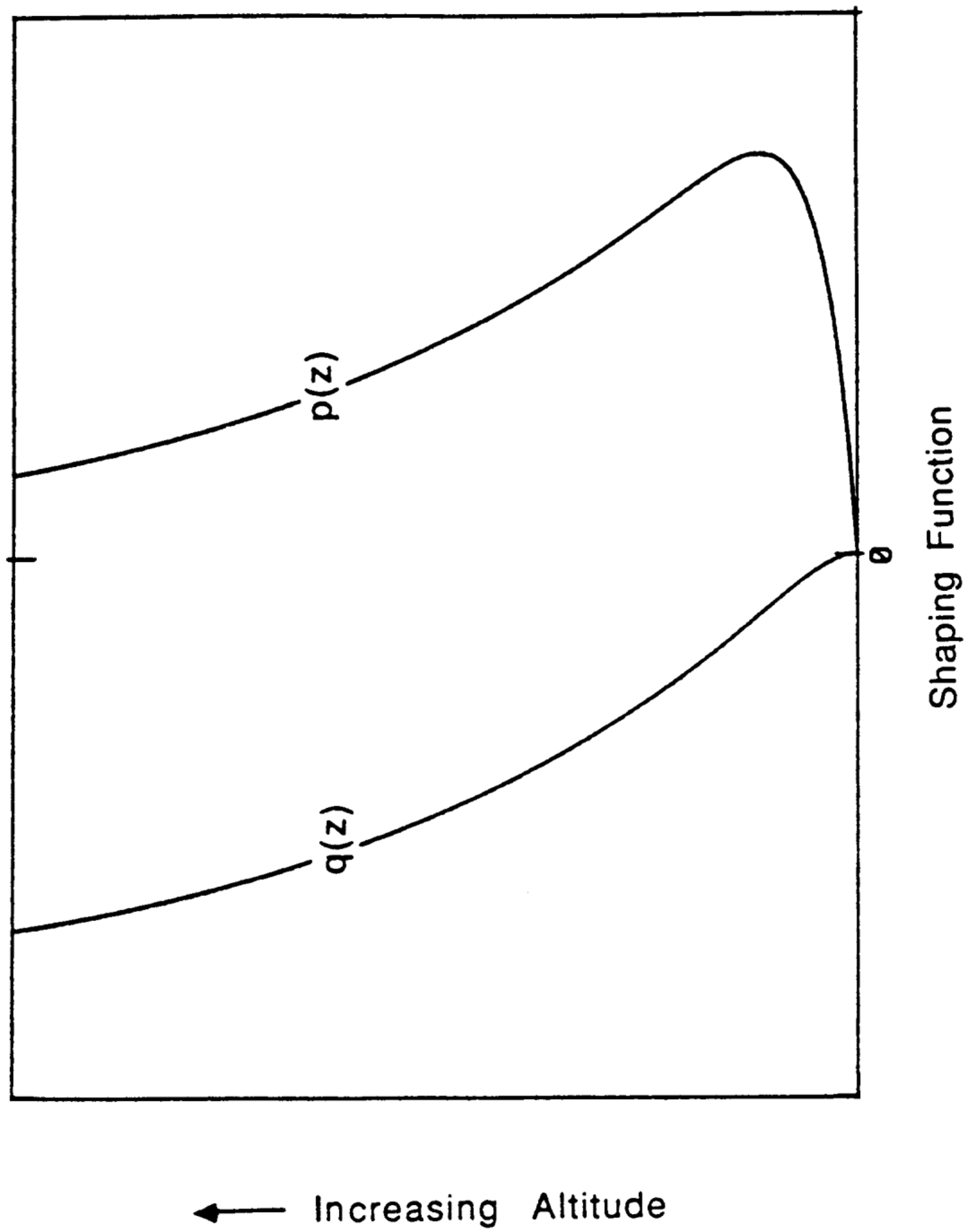


Figure 5. Characteristic Variation of Vertical Shaping Functions

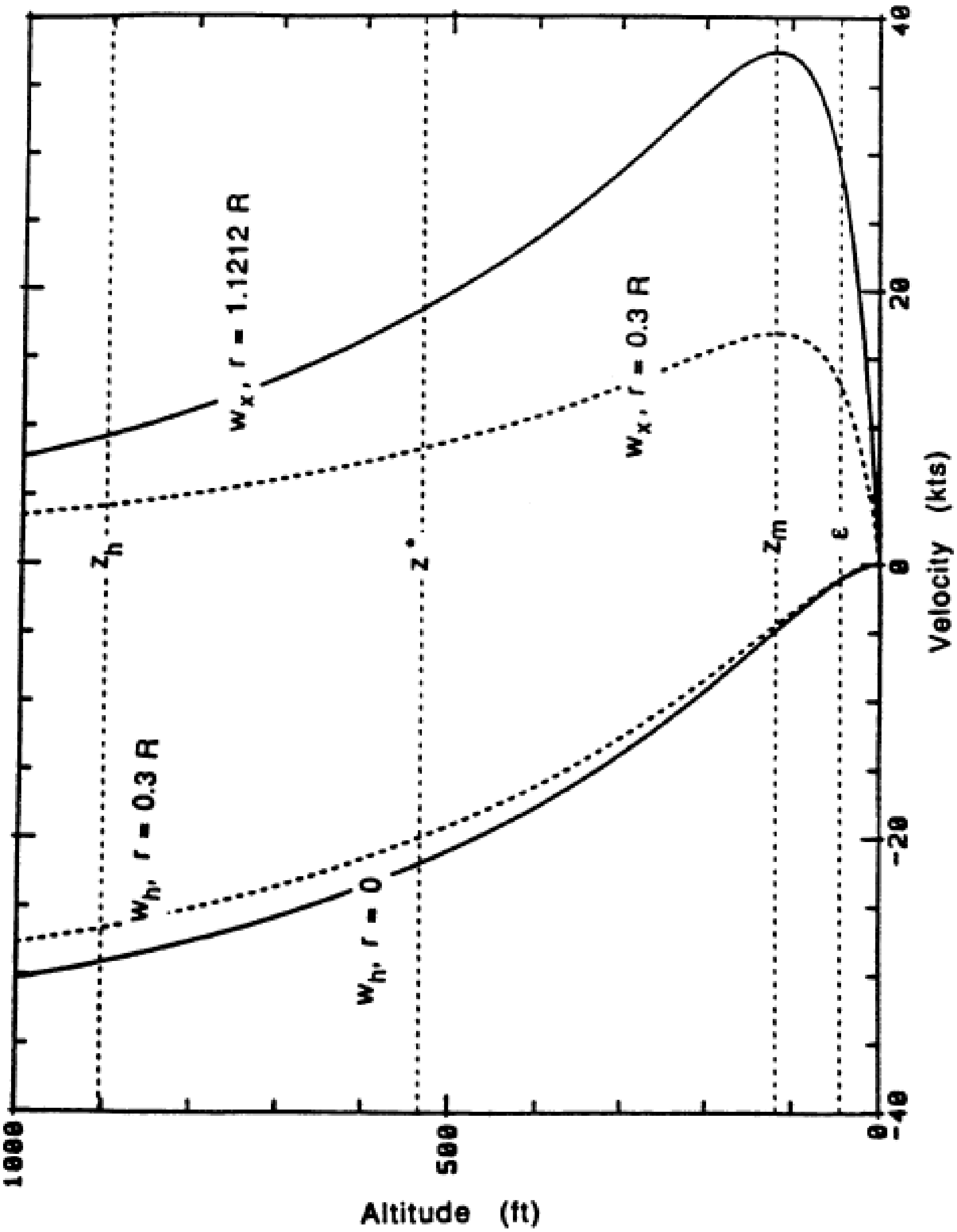


Figure 6. Vertical Velocity Profiles For Analytical Model

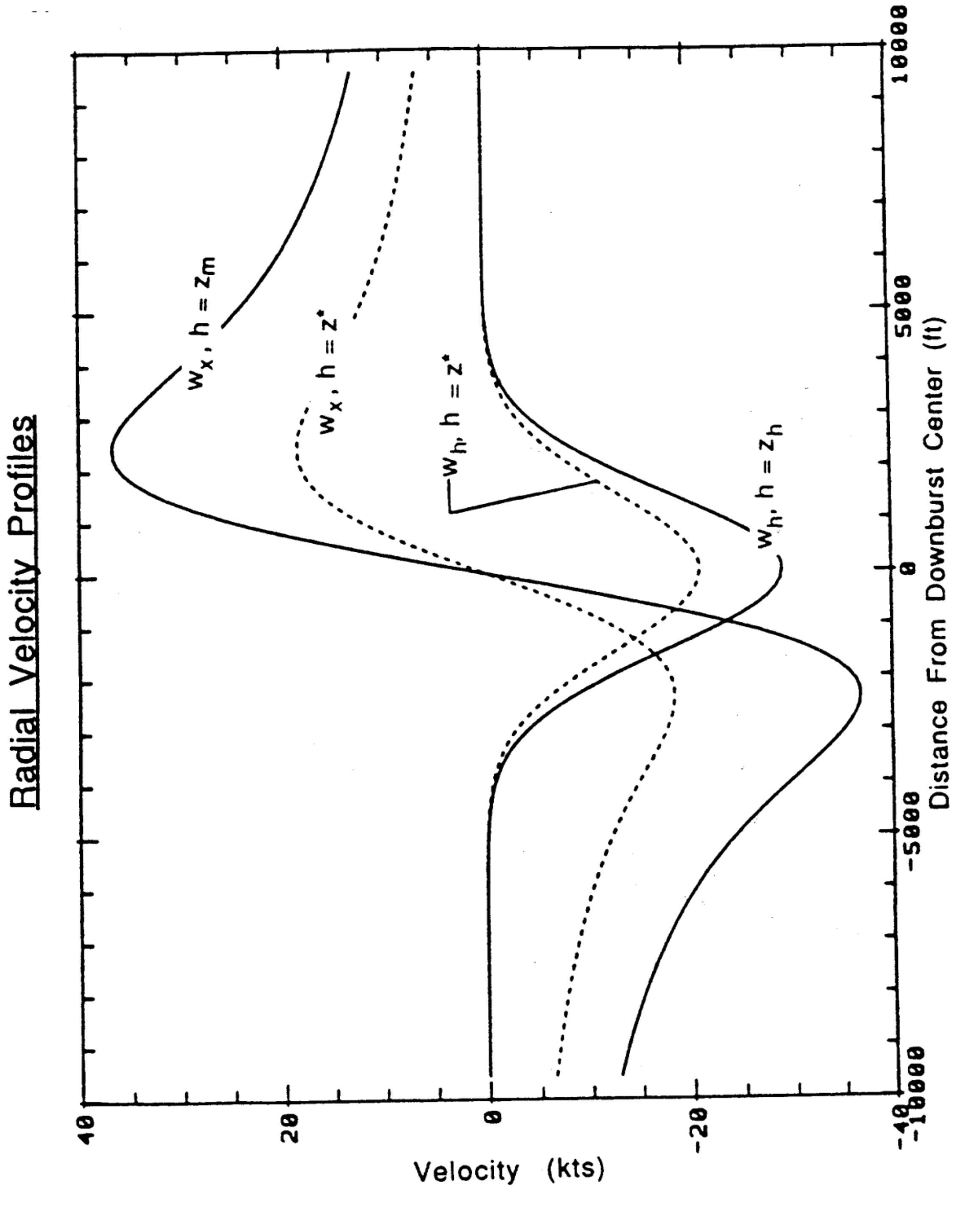


Figure 7. Radial Velocity Profiles For Analytical Model

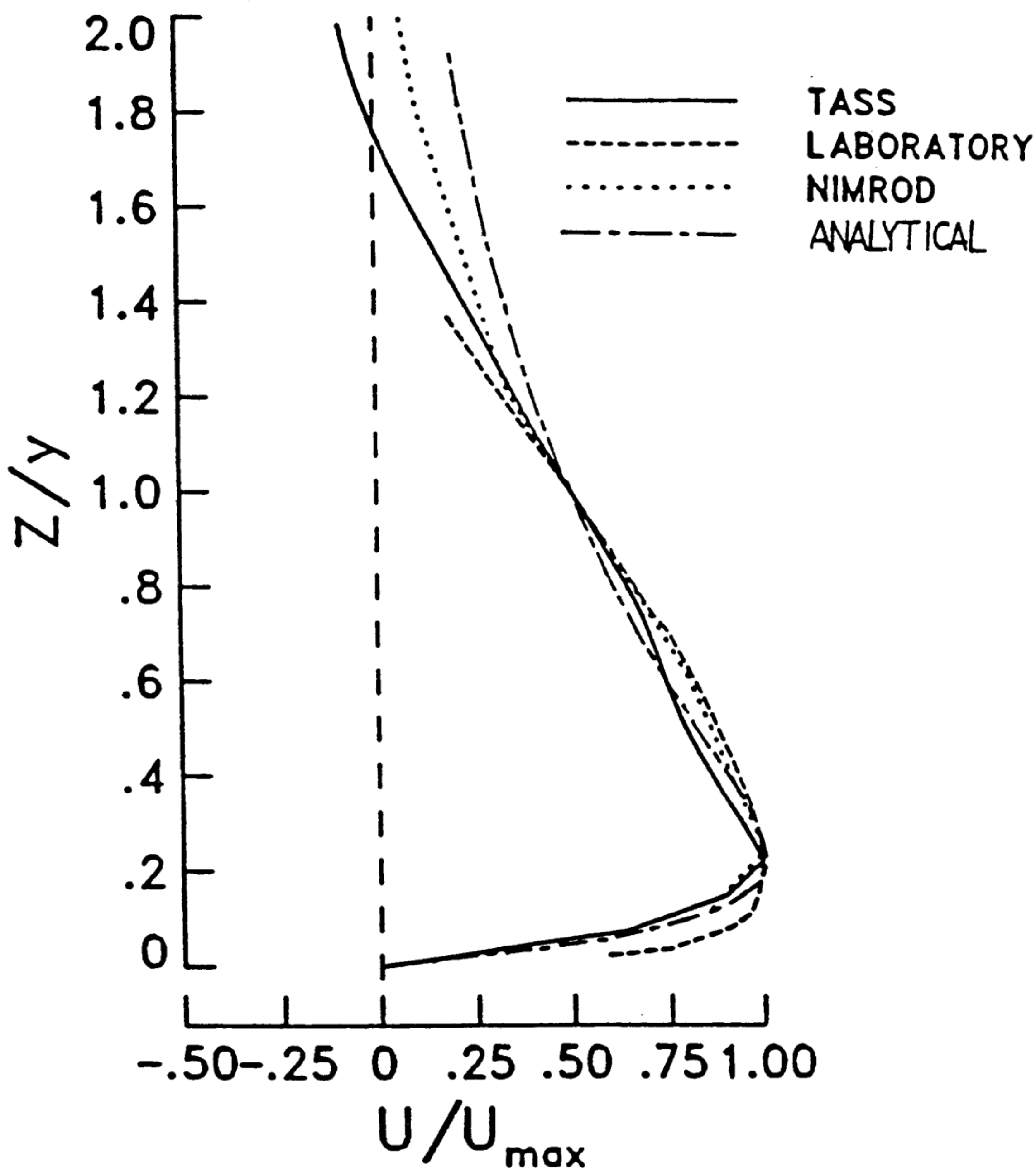


Figure 8. Comparison of Wind Model Vertical Profiles

APPENDIX 4

This appendix contains data that defines the Dryden turbulence model and discrete gust model to be used in conduction the tests specified in paragraphs (d)(7)(ii), (d)(7)(iii), (d)(8)(ii), and (d)(8)(iii) of appendix **1** of this TSO.

Dryden Turbulence Model

Fu(S) = SIGMAu * SQRT (TAUu/PI) * 1/(1+TAUu*S)

$$Fv(S) = SIGMAv * SQRT(TAUv/PI2) * \frac{(1 + SQRT3*TAUv*S)}{(1 + TAUv*S)*(1 + TAUv*S)}$$

$$Fw(S) = SIGMAw * SQRT(TAUw/PI2) * \frac{(1 + SQRT3*TAUw*S)}{(1 + TAUw*S)*(1 + TAUw*S)}$$

where:

SIGMAu, SIGMAv, SIGMAw are the RMS intensities;
TAUu = Lu/VA;
TAUv = Lv/VA;
TAUw = Lw/VA;
Lu, Lv, Lw are the turbulence scale lengths;
VA is the aircraft's true airspeed (ft/sec);
PI = 3.1415926535;
PI2 = 6.2831853070 (2 times PI);
SQRT3 = 1.732050808 (square root of 3); and
S is the Laplace transform variable.

The following table lists SIGMAu, SIGMAv, SIGMAw, Lu, Lv, and Lw versus altitude. Extrapolation will not be used, and simulator altitudes outside the bounds of the turbulence list will use the data at the boundary.

Altitude	RMS Intensities (ft/sec)			Scale Lengths (feet)		
(feet)	Long	Lat	Vert	Long	Lat	Vert
100	5.6	5.6	3.5	260	260	100
300	5.15	5.15	3.85	540	540	300
700	5.0	5.0	4.3	950	950	700
900	5.0	5.0	4.45	1123	1123	900
1500	4.85	4.85	4.7	1579	1579	1500

The applicant must demonstrate that the variance of their turbulence implementation is adequate.

Discrete Gust Rejection

Discrete gusts (in the horizontal axis) with ranges of amplitude and frequency (A and OMEGA) of the form [A(1 − cos OMEGAt)] must be used. The following table lists the values of A and OMEGA to be used (simulates an approximate15 knot gust condition):

A	OMEGA (rad/sec)	Approx. Gust Duration (sec)
7.5	2.10	3
7.5	1.26	5
7.5	0.78	8
7.5	0.63	10
7.5	0.52	12
7.5	0.42	15
7.5	0.31	20

APPENDIX 5
SHEAR INTENSITY

$$f(t) = \frac{\dot{w}_x}{g} - \frac{W_h}{V}$$

where

$\dot{w}_x$ = Horizontal component of the wind rate of change expressed in g units (1.91 kts/sec = 0.1 g) (positive for increasing headwind).

W_h = Vertical component of the wind vector w (ft/sec) (positive for downdraft).

V = True airspeed (ft/sec).

g = Gravitational acceleration (ft/sec^2).

APPENDIX 6

The following computer listing (written in QuickBasic) provides a simplified aircraft simulation model for evaluating the effectiveness of various guidance schemes. This simulation runs on a personal computer, and the results obtained using it have been found to be comparable to those obtained on a full six degree of freedom simulator. This model was developed by J. Rene Barrios of the Honeywell Company.

The Wind Shear Simulation Model (WSSM) is a point mass three-degree of freedom mathematical model which simulates the motion of an aircraft in a vertical plane. The equations of motion, which are described in the wind axes, include the wind components of velocity and acceleration so that the aircraft dynamics during a windshear encounter are accurately modeled. This model has been used by several investigators to study the behavior of an aircraft during windshear encounters.

> **Note:** The Wind Shear Simulation Model provided at the end of this Appendix 6 is an example written in Microsoft QuickBasic. Other programming languages such as Microsoft FORTRAN, C, of assembly language are also acceptable.

The Equations of Motion

The motion of a constant mass point in the vertical plane may be described by four equations of state and a control variable. For an aircraft it is convenient to use an orthogonal reference frame which is attached to the frame of the aircraft and its x-direction points in the direction of motion. Such a reference frame is the relative wind reference frame.

The following equations model the states of the aircraft in the wind axes:

$$\mathrm{Vdt} = g[(\mathrm{T.csalf}) - \mathrm{D})/\mathrm{W} - \mathrm{sngam}] - \mathrm{Wxdt.csgam} - \mathrm{Wzdt.sngam} \qquad (1)$$

$$\mathrm{Gdt} = \{g[(\mathrm{T.snalf} + \mathrm{L})/\mathrm{W} - \mathrm{csgam}] + \mathrm{Wxdt.sngam} - \mathrm{Wzdt.csgam}\}/\mathrm{V} \qquad (2)$$

$$\mathrm{Hdt} = \mathrm{V.sngam} + \mathrm{Wz} \qquad (3)$$

$$\mathrm{Xdt} = \mathrm{V.csgam} + \mathrm{Wx} \qquad (4)$$

Where:

Vdt	=	Rate of change of true airspeed in knots/sec
g	=	Gravitational constant in knots/sec
T	=	Total engine thrust in lbs.
csalf	=	cos (alpha)
alpha	=	Angle of attack in radians
D	=	Total drag in lbs.
W	=	Gross weight in lbs.
sngam	=	sin (gamma)
gamma	=	Flight path angle in radians
Wxdt	=	Inertial windshear x-component in knots/sec
Gdt	=	Rate of change of gamma in rad/sec
snalf	=	sin (alpha)

L	=	Total lift in lbs.
V	=	True airspeed in knots
Hdt	=	Altitude rate in knots
Wz	=	Inertial wind z-component in knots
Xdt	=	Ground speed in knots

In the above equations, positive directions are upwards and forwards. This implies that tail winds and updrafts are positive while head winds and downdrafts are negative. All states can be determined from a given alpha; therefore, alpha is the control variable.

Since the model is that of a point mass, it is necessary to introduce the concept of alpha_command and actual alpha to account for the effect of the horizontal tail/elevator. This is done by introducing a lag between alpha_command and the actual alpha. Therefore, any command that is given to the elevator or stabilizer can be interpreted as an alpha_command which will cause a change in angle of attack.

From equations 1, 2, 3, and 4 it can be seen that any change in alpha will produce a change in the longitudinal and normal accelerations which in turn will change the states of the aircraft.

<u>The Path Control Function</u>

The different segments of the trajectory flown by the WSSM are described by a series of alpha_commands which are generated by the procedure explained below.

1. The aircraft is trimmed for the initial conditions specified by the user. Initial conditions are usually specified as altitude, gross weight, flaps, speed, flight path angle, and wind characteristics. The trimming operation consists in finding the angle of attack that satisfies the equations of state and will result in an unaccelerated motion.

2. After the initial trim, alpha_command must be specified for each segment of the trajectory, which usually consists of a climb or descent segment at constant speed of constant path angle, and guidance through wind disturbances. The wind disturbance is provided by wind models that can be selected at initialization time.

3. In order to specify an alpha_command the user must supply a subroutine where a quadratic function is defined in such a way that when minimized with respect to alpha, and constrained by the equations of state, the minimizing alpha will produce the desired path in an optimal manner. For example, if we want to fly initially at a constant path angle, say 8 degrees, then the quadratic function may be defined by the expression:

$$\text{cst} = (\text{gamma} + \text{Gdt*dt} - 8/57.3)^2 \qquad (5)$$

where:

cst = Function to be minimized w/r/t alpha
dt = Time increment used in simulation in sec.

The term Gdt*dt is a predictive term which anticipates the change in gamma.

Other expressions follow:

$$\text{cst} = (\text{V} + \text{Vdt*dt} - \text{V\_cmd})^2 \qquad \text{Constant speed}$$

$$\text{cst} = (\text{alpha} + \text{gamma} + \text{Gdt*dt} - \text{pitch\_cmd})^2 \qquad \text{Constant pitch}$$

The minimization of the function cst is performed by a subroutine at each time frame and is totally transparent to the user, who has to supply only the objective function cst.

4. Each expression defining a different value of the objective function cst is called a "LAW". The user selects the guidance law to be used during the windshear encounter at menua time. This method allows the user to compare different guidance laws under the exact same conditions.

The Wind Models

The WSSM has two types of wind models: the Dallas-Ft Worth accident wind field simulated by a quad_vortex model, and the constant shear model which is user defined via the initial conditions menu.

Plotting Capabilities

The WSSM can plot up to 3 runs with 10 parameters per run. The length of each run should be kept under 60 seconds. This feature allows the user to compare different trajectories by overlaying the results.

The Program

The WSSM is written in Microsoft QuickBasic which is a highly structured language with a very friendly full page editor. QuickBasic is very convenient for development since it allows the user to stop execution, change the program and continue executing. It also interfaces with Microsoft FORTRAN, C, of assembly language.

The procedure suggested for this application is that the WSSM be compiled without subroutines DETECT and GUIDE. DETECT and GUIDE can be separately compiled and put in a library called WNDSHR.QLB. These external subroutines may be written in Microsoft FORTRAN, C, or assembly language.

```
'************ AIRCRAFT FLIGHT PROFILE SIMULAITON **********
'
'

DECLARE SUB PLOT ( )
DECLARE SUB TAKEOFF ( )
DECLARE SUB EULER ( )
DECLARE SUB MCRBRST ( )
DECLARE SUB WINDS ( )
DECLARE SUB OPT ( )
DECLARE SUB MIN (DM, M2, C1, C2, C3, M)
DECLARE SUB BEGIN ( )
DECLARE SUB VSHAKER ( )
DECLARE SUB COST ( )
DECLARE SUB LIMIT ( )
DECLARE SUB RATES ( )
DECLARE SUB THRUST ( )
DECLARE SUB ATMOS ( )
DECLARE SUB PRINTS ( )
DECLARE SUB DRAGS ( )

COMMON SHARED FLPS%, GEAR%, GEAR$, CL, CD, LIFT, DRAG, ALPHA
COMMON SHARED SEC, ALT, DST, HDOT, ALF, GAM, GAMREF, GREF, G
COMMON SHARED WSALERT%, WXO, WL, WX, WXDT, WZ, WZDT, DFW
COMMON SHARED WV, LC%, GM, GREFF, NOSAVE, GMO
COMMON SHARED DELTA, ISA, T0, SPDSND, VT, VC, MACH, A0, TAT, TAMF
COMMON SHARED THRST, EPR, TFCT, APPFLG%
COMMON SHARED SNGM, CSGM, CSAL, SNAL, VDOT, WG, GDOT, XDOT
COMMON SHARED AWX, AWZ, AU, AZ, VG, GRND, KF1, GMIN, KF2
COMMON SHARED ACMD, OLDALF, DT, HP, LP, ALFLIM
COMMON SHARED LAW%, GMR, ASS, CST, VTO, GCMD
COMMON SHARED OUTFILE$, DM, ALT1, PL$, TTT, WXDTO, TDX, TSH, WZO,
TDZ, TSV
COMMON SHARED GM1, VTP, THETA
COMMON SHARED ALFRTE, PLMFLG%

'******************************************
'              MAIN PROGRAM  *
'******************************************

START:  '< ----------------<<        RE-RUNS START HERE

CLOSE  :  CLEAR
COLOR  15,  1:  CLS  :  VIEW PRINT
```

```
        LOCATE 8, 23:  PRINT "WINDSHEAR SIMULATION"
        LOCATE 10, 23: PRINT "FOR                    "
        LOCATE 12, 23: PRINT "BOEING 737/200         "
        LOCATE 23, 23: PRINT "TYPE " + CHR$(&H22) + "I" + CHR$(&H22) + "
FOR INFORMATION"
        DO WHILE a$ = ""
        a$ = INKEY$
    LOOP
    IF a$ = "I" OR a$ = "i" THEN
         a$ = "": CLS
         '----------------------    INFORMATION PAGE----------------------------------------
        LOCATE 2, 2:   PRINT "BOEING 737/200 INFORMATON"
        LOCATE 3, 2:   PRINT "JT8D-17 ENGINES"
        LOCATE 5, 2:   PRINT "----------------------------------------------------------------------"
        LOCATE 7, 2:   PRINT "ALLOWABLE WEIGHT RANGES..................: 75,000 TO
120,000 POUNDS"
        LOCATE 9, 2:   PRINT "ALLOWABLE TAKEOFF FLAP SETTINGS.........: 1, 2,
5, 15, 20, 25 DEGREES"
        LOCATE 11, 2:  PRINT "ALLOWABLE LANDING FLAP SETTINGS.........: 30,
40 DEGREES"
        LOCATE 13, 2:  PRINT "TAKEOFF EPR AT SEA LEVEL, STD. DAY...: 2.1   "
        LOCATE 15, 2:  PRINT "REFERENCE WING AREA.......................: 980 SQUARE
FEET"
        LOCATE 17, 2:  PRINT "REFERENCE TAKEOFF SPEED..................: V2 + 10"
        LOCATE 19, 2:  PRINT "REFERENCE LANDING SPEED..................: 1.3 Vs"
        LOCATE 23, 2:  PRINT "Press Any Key to Continue..."
        DO: LOOP WHILE INKEY$ = ""
END IF
ANS$ = "2"
CLS
WHILE (ANS$ = "2")
    LOCATE 10, 30: PRINT "Fly  ..... 1"
    LOCATE 12, 30: PRINT "Plot ..... 2"
    LOCATE 14, 30: PRINT "Exit ..... 3"
    LOCATE 18, 30: INPUT "Selection .....";  ANS$
    IF ANS$ = "2" THEN
                            CALL PLOT
                            COLOR 15, 1
                            CLS
    END IF
WEND
IF ANS$ = "3" THEN END
CALL BEGIN      'GET DATA/INITIALIZE VARIABLES
CALL THRUST     'INITALIZE THRUST
CALL TAKEOFF    'INITALIZE TAKEOFF
```

```
CALL  COST         'SUBROUTINE  COST
CALL  PRINTS       'SUBROUTINE  PRINT

      FOR  ICL%  =  1  TO  TTT ' TTT  IS  THE  RUN  TIME  IN  SECONDS

             CALL  THRUST      ' SUBROUTINE  EPR/THRUST
             CALL  WINDS       ' SUBROUTINE  WINDS
'             CALL  DETECT      ' SUBROUTINE  WINDSHEAR  DETECTION
                               ' SUPPLIED  BY  USER
                               ' MUST RESIDE IN LIBRARY WNDSHR.QLB
             CALL  OPT   ' SUBROUTINE  OPTIMIZE
             CALL  LIMIT' SUBROUTINE  ALPHA  RATE
             CALL  EULER       ' SUBROUTINE  INTEGRATE
             CALL  ATMOS       ' SUBROUTINE  ATMOSPHERE
             CALL  PRINTS      ' SUBROUTINE  PRINT
             IF  ALT  <  0  THEN  EXIT  FOR

      NEXT  ICL%

      PRINT  "RUN IS COMPLETE"
      PRINT  "TYPE  "  +  CHR$(&H22)  +  "D"  +  CHR$(&H22)  +  "  FOR RUN DATA"
      a$  =  ""

      DO  WHILE  a$  =  "" ' Wait  for  key  to  be  pressed
             a$  =  INKEY$
      LOOP
      VIEW  PRINT:  COLOR  15,  4:  CLS
      IF       a$  =  "D"  OR a$  =  "d"  THEN
             a$  =  ""

             LOCATE  2,  2:  PRINT  "DATA  FROM  CURRENT  RUN"
             LOCATE  4,  2:  PRINT  "-----------------------------------------------------------"
             LOCATE  6,  2:  PRINT  "GROSS  WEIGHT:          ";  WG;  "  POUNDS"
             LOCATE  7,  2:  PRINT  "ISA  DEVIATION:         ";  ISA;  "  DEG  C"
             LOCATE  8,  2:  PRINT  "FLAP  POSITION:         ";  FLPS%;  "  DEGREES"
             LOCATE  9,  2:  PRINT  "GEAR  POSITION:         ";  GEAR$
             LOCATE  11, 2:  PRINT  "CONTROL LAW:            ";  LAW%
             LOCATE  12, 2:  PRINT  "GAMMA REFERENCE:        ";  GAMREF
             LOCATE  13, 2:  PRINT  "PITCH  LIMITING:        ";  PL$

             IF  PL$  =  "YES"  THEN
             LOCATE  14, 2:  PRINT  "MAXIMUM PITCH:          ";  HP  *  57.3;  "
DEGREES"
             LOCATE  15, 2:  PRINT  "MINIMUM PITCH:          ";  LP  *  57.3;  "
DEGREES"
```

```
            END IF

            LOCATE 16, 2: PRINT "TIME OF RUN:          "; TTT * DT; "
SECONDS"

            IF DFW = 1 THEN
            LOCATE 17, 2: PRINT "DALLAS/FW Wind Model"
            ELSE
            LOCATE 17, 2: PRINT "HORIZ. WIND MAGNITUDE    "; WXO; "
KNOTS"
            LOCATE 18, 2: PRINT "HORIZ. SHEAR MAGNITUDE:  "; WXDTO; "
KNOTS/SECOND"
            LOCATE 19, 2: PRINT "HORIZ. SHEAR DURATION:   "; TDX; "
SECONDS"
            LOCATE 20, 2: PRINT "VERT.   WIND MAGNITUDE:   "; WZO  *
1.689;    "  FT/SECOND"
            LOCATE 21, 2: PRINT "VERT.   WIND DURATION:    "; TDZ; "
SECONDS"
            LOCATE 22, 2: PRINT "------------------------------------------------------------"
            END IF

            IF LEN(OUTFILE$) = 0 THEN OUTFILE$ = "NONE"
            LOCATE 23, 2: PRINT "OUTPUT FILE:          "; OUTFILE$
            LOCATE 24, 2: PRINT "Press Any Key to Continue...."

            DO: LOOP WHILE INKEY$ = ""                'Wait for key to be pressed

      END IF

      GOTO START
      END

SUB ATMOS STATIC


      '****************************************************
      '                SUBROUTINE ATMOSPHERE               *
      '****************************************************

      STATIC THETA

      L% = ALT > 36089!
      FISA = 1.8 * ISA

      IF ALT > 36089 THEN
```

```
                    TMP = .7519 * T0
                    DELTA = .2234 * EXP((36089! - ALT) / 20806)
             ELSE
                    TMP = T0 - .0035662 * ALT
                    DELTA = (TMP / T0)  ^  5.256
    END IF

    TAMB = TMP + FISA                  'TAMBient in deg.  R
    TAMF = TAMB - 459.7                '     "      "     F
    THETA = TAMB / T0
    SQRTH = SQR(THETA)
    SPDSND = A0 * SQRTH

    IF VT > 0 THEN MACH = VT / SPDSND

    VC = A0 * SQR(5 * (((1 + MACH * MACH / 5) ^ 3.5 - 1) * DELTA + 1) ^
.28571 - 5)
    TAX = (TMP + FISA) * (1 + .2 * MACH * MACH) 'Deg. R
    TAT = 5 * (TAX - 459.7 - 32) / 9              'Deg. C

    IF INKEY$ < > "" THEN PRINT : INPUT "Press ENTER to continue....";  XXX

END SUB

SUB BEGIN STATIC
    CLS : VIEW PRINT

    '<--------------------------------  DATA_INPUT  ----------------------------->

    PRINT
    INPUT "OUTPUT FILE (DEFAULT IS NO FILE) "; OUTFILE$

    IF OUTFILE$ = " " THEN
                    NOSAVE = 1
               ELSE
                    NOSAVE = 0
    END IF

    ' CONSTANTS USED IN CALCULATIONS:

    A0 = 661.478599#        'Speed of sound at sea level in knots
    G = 19.07583                 'Gravitational constant in knots/sec
    T0 = 518.67             'Standard temperature at SL in deg Rankine
    DT = .25                'Simulation time step in seconds
```

```
' --------------------------------  INITIALIZATION  OF  VARIABLES-----------------------
---

GMIN  =  0
VDOT  =  0
ALT1  =  0
INPUT  "TAKEOFF  OR  APPROACH   (T/A)     (Default  is  T).....";  ANS$

IF  ANS$  =  "a"  OR  ANS$  =  "A"  THEN
                                   INPUT  "ENTER  ALTITUDE  IN  FEET
    (Default  is  1000' . ";  ALT1
                                   IF ALT1  =  0  THEN  ALT1  =  1000
                                   APPFLG%  =  1
                                   TFCT  =  1
END  IF
ALT  =  ALT1

' ----------------------   CONFIGURTATION  CONSTANTS---------------------------------
--------

ASS  =  16.5                                       'Stick  Shaker  alpha  in
degrees
ASS  =  ASS  /  57.3                               '    "        "        "
"radians

' ----------------------------------------   GROSS  WEIGHT  ENTRY------------------------
-----------------

PRINT  :  INPUT  "ENTER  GROSS  WEIGHT  IN  POUNDS  (Default  is  110000)  ";
WG
IF  WG  =  0  THEN  WG  =  110000!                 '  DEFAULT  SETTING

FL%  =  0

WHILE  (NOT  FL%)

    INPUT  "ENTER  FLAPS  SETTING                  (Default  is   0).............";
FLPS%

    SELECT  CASE  FLPS%
    CASE  0,  1,  2,  5,  15,  20,  25,  30,  40
        FL%  =  -1
    CASE  ELSE
        FL%  =  0
        PRINT  "Invalid  flaps  setting"
```

```
                PRINT "Only 0, 1, 2, 5, 15, 20, 25, 30, & 40 are supported"
                PRINT
        END SELECT

    WEND


    IF FLPS% < 15 THEN GEAR% = 1
    IF FLPS% = 15 THEN INPUT "GEAR UP OR DOWN       (1/0) (Default is
Down).....";  GEAR%
    IF GEAR% = 1 THEN
                    GEAR$ = " UP"
                ELSE
                    GEAR$ = " DOWN"

    END IF
    INPUT "ENTER ISA DEV. IN DEGREES C    (Default is 0)......"; ISA

    PRINT

    CALL VSHAKER           ' COMPUTE V2+10 FOR FLAPS<33 OR 1.3Vs FOR
FLAPS>32

    PRINT " CONTROL LAW SELECTION:"
    PRINT
    PRINT " Speed = 1.1* V_stall      = 1"
    PRINT " Alpha = Stick Shaker Alpha = 2"
    PRINT " Horizontal Acceleration = 0  = 3"
    PRINT " 15_Degree Pitch           = 4"
    PRINT " Theoretical HONEYWELL/SPERRY = 5"
    PRINT " User Defined              = 6"
    PRINT
    INPUT " SELECT CONTROL LAW ....................... "; LAW%

        IF LAW% = 0 THEN LAW% = 5

        PRINT : PRINT

        ' ---------------------------------- GAMMA REFERENCE INPUT-------------------
--------------

        IF LAW% > 4 THEN
                INPUT "ENTER GAMMA REFERENCE IN DEGREES (Default is
0).........";  GMR
                PRINT
```

```
            GAMREF = GMR
            GMR = GMR / 57.3: GMIN = GMR
        END IF

        ' -------------------------------------- PITCH LIMITING SELECTION--------------
-------------------------------

        INPUT "PITCH LIMITING DESIRED (y/n) (Default is NO)..............."; PL$

        IF PL$ = "Y" OR PL$ = "y" THEN

            PL$ = "YES"
            INPUT "      MAXIMUM PITCH ALLOWED IN DEGREES "; HP
            INPUT "      MINIMUM PITCH ALLOWED IN DEGREES "; LP
            HP = HP / 57.3: LP = LP / 57.3: PL% = 1

        ELSE

        HP = 100
        LP = -100
        PL% = 0
        PL$ = "NO"

    END IF
    CLS
    ' ---------------------------------------------- TIME FOR RUN---------------------------------
------------------------------
    PRINT
    INPUT "ENTER TIME OF RUN IN SECONDS (Default is 45).............."; TTT
    TTT = TTT / DT
    IF TTT = 0 THEN TTT = 45 / DT              '   DEFAULT SETTING
    ' ------------------------------------ WINDSHEAR SET UP------------------------------------
-----------------
    INPUT "DALLAS/FW Wind Model (y/n)...(Default is constant Shear)....."; ANS$

    IF ANS$ = "Y" OR ANS$ = "y" THEN
    DFW = 1
                                    ELSE
    DFW = 0
    PRINT
    INPUT "MAGNITUED OF HORZ. WIND IN KNOTS......(Head wind < 0)......";
WXO
    INPUT "MAGNITUED OF HORZ. SHEAR IN KT/SEC. (Dec. Perf. > 0)......";
WXDTO
    INPUT "DURATION OF HORZ. SHEAR IN SEC.............(Default is 0)......"; TDX
```

```
      INPUT "TIME FOR SHEAR TO START IN SEC..............(Default is 0)......"; TSH
      PRINT

      INPUT "MAGNITUED OF VERT. WIND IN FT/SEC. (Down Draft < 0)......";
WZO
      WZO = WZO / 1.689                    'Convert to knots
      INPUT "DURATION  OF VERT. WIND IN SEC...........(Default is 0)........"; TDZ
      INPUT "TIME FOR SHEAR TO START IN SEC...........(Default is 0)......"; TSV
      PRINT
      END IF

      ' --------------------  OTHER SET UPS---------------------------------------------------
      VT = VTO
      WX = WXO

      CALL ATMOS              ' SUBROUTINE ATMOSPHERE

      ' ----------------------------------  HEADERS FOR SCREEN DISPLAY---------------------
-------------------------------
      CLS : PRINT
      PRINT "TIME   ALT   HDOT   VT   ALPHA   GAMMA   PITCH   GREF   WXDT
WZ   VDOT   ALRT"
      PRINT "(SEC)   (FT)   (FPM)   (KTS) (DEG)   (DEG)   (DEG)   (DEG) (KT/S)
(FPS) (KT/S)"
      PRINT STRING$(75, "-"): VIEW PRINT 5 TO 25
      '***************************************
      '   SUBROUTINE INIT_OUTPUT FILE *
      '***************************************
      IF NOSAVE THEN    ' CREATE OUTPUT FILE
      ELSE
            OPEN "O", 2, OUTFILE$
            FMT$ = " ###.##   #####   #####   ####   ####   ##   ###.##   ###.##
###.##"
            FMT$ = FMT$ + " ###.##   ###.#   ###.#   ##.## "
      END IF

END SUB

SUB COST STATIC

      '***************************************************************
      '                     SUBROUTINE COST              *
      '***************************************************************

      CALL DRAGS                     ' SUBROUTINE DRAG & LIFT
```

```
CALL RATES                    ' SUBROUTINE RATES

IF LC% = 0 THEN               'Constant gamma segment

            FCT = (GM + GDOT * DT - GMO) ^ 2
            GREFF = 57.3 * GMO

        ELSE                  'All guidance laws

    SELECT CASE LAW%

        CASE 1  '----------------------------  1.1*Vstall-------------------------------
----

        CST = (VT + VDOT * DT - 1.1 * 135) ^ 2

        CASE 2  '----------------------------  Alpha = Ass---------------------------
--------

        CST = (ALPHA - ASS) ^ 2

        CASE 3  '----------------------------  Ax = 0---------------------------------
-

        CST = (VDOT - VT * GDOT * GM + WXDT) ^ 2

        CASE 4  '----------------------------  15 Degrees------------------------------
-----

        CST = (GM + 3 * GDOT * DT + ALPHA - 15 / 57.3) ^ 2

        CASE 5  '----------------------------  User Defined--------------------------
--------

            PRINT "Not defined"
            STOP

        CASE 6  '----------------------------  User Supplied-------------------------
---------

'User must supply a subroutine called GUIDE
'which must reside in the WNDSHR.QLB Library
'GUIDE can have a list of arguments
```

```
'As an example

'ALF = 57.3*ALPHA
'PTH = 57.3 * (ALPHA + GM)

' units :    ft    fpm   kt   deg   deg   g's  g's  *

'CALL GUIDE(ALT, HDOT, VC, ALF, PTH, AU, AZ, CST)

        END SELECT
END IF

'       CST is the Cost Function to be minimized

END SUB

SUB DRAGS STATIC
        '*****************************************************
        '       SUBROUTINE DRAG   FOR B737/200       *
        '*****************************************************
        X = 57.3 * ALPHA + 1

        CF5 = 0: CF4 = 0: CF3 = 0: CF2 = 0

        SELECT CASE FLPS%

CASE 0
        CF1 = .091
        CF0 = .0156
CASE 1
        CF3 = -1.164058E-04
        CF2 = 2.48561E-03
        CF1 = .0905781
        CF0 = .062114

CASE 2
        CF0 = .101198
        CF1 = .110993
        CF2 = -.0015162
        CF3 = 1.8931E-04
        CF4 = -7.1427E-06
        CF5 = -4.2776E-09

CASE 5
        CF0 = .192638
```

```
        CF1  =  .123509
        CF2  =  -.0051477
        CF3  =  6.4968E-04
        CF4  =  -3.0891E-05
        CF5  =  4.1291E-07

CASE  10
        CF0  =  .249855
        CF1  =  .114005
        CF2  =  7.1207E-04
        CF3  =  -9.9541E-05
        CF4  =  7.0431E-06
        CF5  =  -2.3773E-07

CASE  15
        CF0  =  .40149
        CF1  =  .118723
        CF2  =  -6.4877E-04
        CF3  =  6.6281E-05
        CF4  =  -1.6113E-07
        CF5  =  -1.4278E-07

CASE  25
        CF0  =  .592655
        CF1  =  .122433
        CF2  =  -.0026365
        CF3  =  3.5963E-04
        CF4  =  -1.5579E-05
        CF5  =  1.0894E-07

CASE  30
        IF  X  <  4  THEN
                                        CF1  =  .12
                                        CF0  =  .72
                                ELSE
                                        CF3  =  -1.651192E-04
                                        CF2  =  4.16461E-03
                                        CF1  =  8.337061E-02
                                        CF0  =  .8350316
END  IF

CASE  40
        IF  X  <  4  THEN
                                        CF1  =  .12
                                        CF0  =  1.08
```

```
                              ELSE
                                  CF3 = -1.689903E-04
                                  CF2 = 3.733285E-03
                                  CF1 = 8.483822E-02
                                  CF0 = 1.201596
    END IF

    CASE ELSE
        PRINT "Flaps "; FLPS%; " not available....."
        END

    END SELECT                'For CL computation

    CL = ((((CF5 * X + CF4) * X + CF3) * X + CF2) * X + CF1) * X + CF0


    SELECT CASE FLPS%         'Low Speed Drag Polars

    CASE 0
        D0 = .013285: D1 = .052868: D2 = -.07182: D3 = .071561

    CASE 1
        D0 = .026143: D1 = .022358: D2 = -.00083: D3 = .016338

    CASE 2
        D0 = .070346: D1 = -.0852: D2 =.097453: D3 = -.01207

    CASE 5
        D0 = .045214: D1 = -.0178: D2 =.04373: D3 = .002101

    CASE 10
        D0 = -.04266: D1 = .19643: D2 = -.1152: D3 = .03966

    CASE 15

        IF GEAR% = 0 THEN
                                      D0 = .034954: D1 = .098892: D2
= -.04187: D3 = .020496
                                  ELSE
                                      D0 = -.02822: D1 = .174631: D2
= -.0874: D3 = .029566
    END IF
    CASE 25
        D0 = -.10416: D1 = .327506: D2 = -.17059: D3 = .043313
    CASE 30
```

```
        D0 = .124697: D1 = -.03348: D2 =.055295: D3 = -.00311
    CASE 40
        D0 = .124925: D1 = .052537: D2 =.006912: D3 = .0058

    CASE ELSE
        PRINT "Flaps "; FLPS% " not available...."
        END

    END SELECT
    CD = ((D3 * CL + D2) * CL + D1) * CL + D0
    Q = 1451770 * MACH * MACH * DELTA          'B737/200
    LIFT = Q * CL
    DRAG = Q * CD
    END SUB

SUB EULER STATIC

    '****************************************************************
    '       SUBROUTINE EULER'S PREDICTOR/CORRECTOR            *
    '             (INTEGRATION SUBROUTINE)              *
    '****************************************************************
    DTH = DT / 3600: DTM = DT / 60: SEC = SEC + DT: VTP = VT

    CALL RATES      ' SUBROUTINE RATES   <<PREDICTOR>>

    ALT1 = ALT: HDOT1 = HDOT: ALT = ALT + HDOT * DTM
    GM1 = GM: GDOT1 = GDOT: GM = GM + GDOT * DT
    DST1 = DST: XDOT1 = XDOT: DST = DST + XDOT * DTH
    VT1 = VT: VDOT1 = VDOT: VT = VT + VDOT * DT

    CALL RATES      ' SUBROUTINE RATES   <<CORRECTOR>>

    ALT = ALT1 + (HDOT1 + HDOT) * DTM / 2
    GM = GM1 + (GDOT1 + GDOT) * DT / 2
    DST = DST1 + (XDOT1 + XDOT) * DTH /2
    VT = VT1 + (VDOT1 + VDOT) * DT / 2

END SUB

SUB LIMIT STATIC


    '***********************************************************************
******
```

```
'                SUBROUTINE ALPHA DOT AND PITCH LIMIT              *
'***********************************************************************
******

ALPHA = OLDALF + .25 * (ACMD - OLDALF)      'Pitch dynamics

CALL DRAGS        ' SUBROUTINE DRAG (REQ'D FOR RATE SUB CALL)

IF PLMFLG% = 0 THEN EXIT SUB

OLDGM = GM
PLIM% = 0

DO WHILE (PLIM% = 0)

CALL RATES        ' SUBROUTINE RATES

X = ALPHA + OLGM + GDOT * DT
IF X > HP THEN ALPHA = .9 * ALPHA
IF X < LP THEN ALPHA = 1.1 * ALPHA
IF ALPHA > ALFLIM THEN
                    ALPHA = ALFLIM
                    PLIM% = 1
END IF
LOOP

END SUB

SUB MCRBRST STATIC

IF MU1 = 0 THEN
               MU1 = -37141!
               AV = 5500: H1 = 2500: G3 = 3: J1 = -700: J2 = 800: J3
= 6.5
               MU2 = -20000
               BV = 12000: H2 = 2000: N1 = 200: N2 = 2500: N3 = 4
               WX = 5
               IF ALT > 1000 THEN
                              PRINT
                              PRINT " DFW data not available above
1000'"
                              PRINT " Please start at or below 1000'"
                              END
               END IF
END IF
```

```
X = 6078 * DST: Y = ALT: A1 = AV: A2 = BV

NX1 = Y - H1: DENX1 = (Y - H1) ^ 2 + (X - A1) ^ 2
NY1 = X + J2 - A1: DENY1 = (Y + J1 - H1) ^ 2 + (X + J2 - A1) ^ 2
NX2 = Y - H2: DENX2 = (Y - H2) ^ 2 + (X - A2) ^ 2
NY2 = X + N2 - A2: DENY2 = (Y + N1 - H2) ^ 2 + (X + N2 - A2) ^ 2
NX3 = Y + H1: DENX3 = (Y + H1) ^ 2 + (X - A1) ^ 2
NY3 = X + J2 - A1: DENY3 = (Y + J1 + H1) ^ 2 + (X + J2 - A1) ^ 2
NX4 = Y + H2: DENX4 = (Y + H2) ^ 2 + (X - A2) ^ 2
NY4 = X + N2 - A2: DENY4 = (Y + N1 + H2) ^ 2 + (X + N2 - A2) ^ 2
XX = MU1 * (-NX1 / DENX1 + NX3 / DENX3) + MU2 * (NX2 / DENX2 -
NX4 / DENX4)
WX = WX + .65 * (XX - WX) + 2 * G3

IF DST = 0 THEN WXP = WX

ZZ = MU1 * (NY1 / DENY1 - NY3 / DENY3) * J3 + MU2 * (-NY2 /
DENY2 + NY4 / DENY4) * N3
WZ = WZ + .65 * (ZZ - WZ)

IF DST = 0 THEN WZP = WZ

WX5 = WX4: WX4 = WX3: WX3 = WX2: WX2 = WX1: WX1 = WX
WZ5 = WZ4: WZ4 = WZ3: WZ3 = WZ2: WZ2 = WZ1: WZ1 = WZ

IF WCNT% < 4 THEN WXDT = (WX - WXP) / DT: WXP = WX
IF WCNT% < 4 THEN WZDT = (WZ - WZP) / DT: WZP = WZ
IF WCNT% > 3 THEN WXDT = (26 * WX5 - 27 * WX4 - 40 * WX3 - 13 *
WX2 + 54 * WX1) / (70 * DT)
IF WCNT% > 3 THEN WZDT = (26 * WZ5 - 27 * WZ4 - 40 * WZ3 - 13 *
WZ2 + 54 * WZ1) / (70 * DT)
IF ABS(WXDT) > 15 THEN WXDT = 15 * SGN(WXDT)
IF ABS(WZDT) > 15 THEN WZDT = 15 * SGN(WZDT)
WCNT% = WCNT% + 1


END SUB

SUB MIN (DM, M2, C1, C2, C3, M) STATIC

'***********************************************************
'SUBROUTINE MIN_CST BY LEAST SQUARES PARABOLA     *
'***********************************************************
ALPHA = M2 + DM                'INCREMENT ALPHA
```

```
    CALL COST                          'SUBROUTINE COST

    IF DM < 0 THEN
        C4 = CST
    ELSE
        SWAP C1, C3
        C5 = CST
    END IF

    ALPHA = M2 - DM              'DECREMENT ALPHA

    CALL COST                    'SUBROUTINE COST

    IF DM < 0 THEN
        C5 = CST
    ELSE
        C4 = CST
    END IF

    M = ABS(DM) * (14 * C1 + 7 * C4 - 7 * C5 - 14 * C3) / (20 * C1 - 10 *
C4 - 20 * C2 - 10 * C5 + 20 * C3)
END SUB

SUB OPT STATIC


    '************************************************************************
*****
    'SUBROUTINE OPTALF - DETERMINES THE ALPHA REQD FOR CMD
GAMMA    *
    '************************************************************************
*****

    OLDALF = ALPHA: GM1 = GM
    CALL ATMOS                   ' SUBROUTINE ATMOSPHERE

    CALL RATES                   ' SUBROUTINE RATES

    DM = 1 / 57.3            ' SET ALPHA INCREMENT TO 1 DEGREE

    C1 = 1E+20
    C2 = 1E+20
    C3 = 1E+20
```

```
OPTFLG% = 0

WHILE (OPTFLG% = 0)

CALL COST               ' SUBROUTINE COST

C3 = C2: C2 = C1: C1 = CST
M3 = M2: M2 = M1: M1 = ALPHA

LGC% = C1 > C2 AND C3 = 1E+20

IF LGC% THEN
            DM = -DM           ' Reverse search direction
            C1 = C2: C2 = CST: M1 = M2: M2 = ALPHA
            ALPHA =ALPHA + 2 * DM
        ELSE
            IF C1 < C2 THEN
                        L% = ABS(OLDALF - ALPHA) / DT >
ALFRTE OR ALPHA > ALFLIM OR ALPHA < -.08
                        IF L% THEN OPTFLG% = 1
                        ALPHA = ALPHA + DM
                    ELSE
                        DM = DM / 2
                        CALL MIN(DM, M2, C1, C2, C3,
M)'Fit parabola & find minimum
                        ALPHA = M2 + M 'This is the optimum
alpha
                        OPTFLG% = 1       'Set flag to terminate
            END IF
END IF
WEND

ALFLIM = ASS                'SET ALPHA LIMIT TO ALPHA STICK
SHAKER

SELECT CASE LAW%

CASE 4
    ALFLIM = ASS - .035 'LIMIT TO SS MINUS 2 DEG
CASE 5, 6
    ALFLIM = ASS - KF2
CASE ELSE
END SELECT
```

```
    IF ALPHA < -.08 THEN ALPHA = -.08
    IF ALPHA > ALFLIM THEN ALPHA = ALFLIM

    ACMD = ALPHA                'SET ALPHA COMMAND TO COMPUTED
ALPHA

END SUB

SUB PLOT

    '***********************************************************************
**************
    '*                      PLOT  ROUTINE                                  *
    '***********************************************************************
**************

    REM $DYNAMIC

'                       TWO DIMENSIONAL PLOTTER

    DEFINT I-L, N

    DIM F$(3)               ' file name array
    DIM DTA(3, 250, 15)           ' data array
    DIM TY$(14)             ' title array (dependant variable)


    TITLE$ = "HONEYWELL WINDSHEAR SIMULATION"     ' main title
    TX$ = "Time (s)"                              '  X  title



    TY$(1) = "Altitude   ft     "
    TY$(2) = "Alt Rate   fpm "
    TY$(3) = "T A S      kts   "
    TY$(4) = "Alpha      deg  "
    TY$(5) = "Gamma      deg  "
    TY$(6) = "Pitch      deg  "
    TY$(7) = "G_ref      deg  "
    TY$(8) = "Hz Shear  kps "
    TY$(9) = "Vt Wind   fps  "
    TY$(10) = "Vt rate   kps  "
    TY$(11) = "W/S Flag       "

    NV = 12
```

```
CLS

LOCATE 3, 15: PRINT "Enter the names of the data files you wish to plot."

FOR NC = 1 TO 3
        LOCATE 6 + 2 * NC, 25                       ' input
        PRINT "FILENAME "; NC; " ";                 ' filenames
        INPUT ; F$(NC)                              ' containing
        IF F$(NC) = " " THEN EXIT FOR               ' data
NEXT NC

NC = NC - 1                                         ' number of curves to plot

LOCATE 20, 15: PRINT "Reading from disk........."


FOR I = 1 TO NC

        CLOSE

        OPEN "I", #1, F$(I)                 ' open file for input

        NP = 0

        DO
                NP = NP + 1                         ' number of points

                FOR J = 1 TO NV

                        INPUT #1, DTA(I, NP, J)     ' read data

                NEXT J

        LOOP UNTIL EOF(1)

        CLOSE
NEXT I


DO ' display all selected parameters

DO ' prompt user until a valid parameter is selected

100     CLS
```

```
        LOCATE 3, 20: PRINT "Select the parameter you wish to plot."

        FOR I = 1 TO NV - 1

        LOCATE 4 + I, 30: PRINT TY$(I); " = "; I

    NEXT I

    LOCATE 21,  30: INPUT "parameter number (0 to exit)"; PARAM%

    IF PARAM% = 0 THEN
        CLS
        EXIT SUB                    ' return to calling program
    END IF

LOOP UNTIL 1 <= PARAM% AND  PARAM% <= 14      'end of select loop

    PARAM% = PARAM% + 1



    DX = 5                  ' x axis grid increment

    GOSUB 400               ' find maximum x and y values

    IF PLTFLG% = 1 THEN
                            PRINT "No information  to plot...."
                            PRINT "Press any key to continue..."
                            DO: LOOP WHILE INKEY$ = ""
                            GOTO 100

    END IF

    GOSUB 600           ' grid and titles

    FOR I = 1 TO NC
        GOSUB 1110          ' plot graph
    NEXT I


    DO
    LOOP WHILE INKEY$ = ""

    CLS : SCREEN 0
```

```
      LOOP

      '**********************************************************************
***************
400   '*                                          MAX  SUBROUTINE
*
      '**********************************************************************
***************
      '
      MAXX  =  DTA(1,  1,  1)
      MAXY  =  DTA(1,  1,  PARAM%)
      MINY  =  DTA(1,  1,  PARAM%)

      FOR  I  =  1  TO  NC
            FOR  J  =  1  TO  NP
                  IF  DTA(I,  J,  1)  >  MAXX  THEN  MAXX  =   DTA(I,  J,  1)
                  IF  DTA(I,  J,  PARAM%)  >  MAXY  THEN  MAXY  =  DTA(I,  J,
PARAM%)

                  IF  DTA(I,  J,  PARAM%)  <  MINY  THEN MINY  =  DTA(I,  J,
PARAM%)

            NEXT  J
      NEXT  I

      PLTFLG%  =  0
      DY  =  (MAXY  -  MINY)  /  15
      IF  DY  =  0  THEN
                        PLTFLG%  =  1
                        DY  =  5

      END  IF
      MAG  =  10  ^  (INT(LOG(DY)  /  LOG(10))):  DY  =  DY  /  MAG

      IF  DY  <=  5  THEN
            DY  =  5
      ELSE
            DY  =  10
      END  IF

      DY  =  DY  *  MAG


      IF  INT(MAXX  /  DX)  < >  MAXX  /  DX  THEN  MAXX  =  INT(MAXX  /  DX  +
1)  *  DX
```

```
    IF INT(MAXY / DY) < > MAXY / DY THEN MAXY = INT(MAXY / DY +
1) * DY

    IF INT(MINY / DY) < > MINY / DY THEN MINY = INT(MINY / DY) * DY


    NUMX = MAXX / DX
    NUMY = (MAXY - MINY) / DY
    RETURN


600
    '***********************************************************************
****************
    '*                    GRID AND TITLES              *
    '***********************************************************************
****************
    '
    CLS
    SCREEN 2                  ' 640*200 monochrome graphics
    KEY OFF
    '
    FOR J = 0 TO NUMX
        Z = J * 580 / NUMX + 59
        LINE (Z, 10) - (Z, 170)        ' vertical grid line
        Z = J * 71 / NUMX + 7

        a = DX * J

        IF a < > 0 THEN                         ' adjustment for
            D = INT(LOG(a) / LOG(10)) + 1       ' large numbers
            IF D > 1 THEN Z = Z - D + 1
        END IF

        LOCATE 23, Z
        PRINT a;
    NEXT J

    FOR J = 0 TO NUMY
    Z = J * 160 / NUMY + 10
    LINE (60, Z) - (640, Z)                    ' horizontal grid line
    Z = 22 - J * 20 / NUMY

    LOCATE Z, 2
```

```
Z = DY * J + MINY

AZ = ABS(Z)

IF INT(Z) = Z THEN
                                        G$ = "######"
ELSEIF AZ < .1 THEN
                                        G$ = "#.####"
ELSEIF AZ >= .1 AND AZ < 1 THEN
                                        G$ = "##.###"
ELSEIF AZ >= 1 AND AZ < 10 THEN
                                        G$ = "###.##"
ELSEIF AZ >= 10 AND AZ < 100 THEN
                                        G$ = "####.#"
ELSE
                                        G$ = "######"
END IF

PRINT USING G$; Z;

NEXT J

Z = (80 - LEN(TITLE$)) / 2 + 2
LOCATE 1, Z: PRINT TITLE$ ' print main title

LOCATE 24, 36: PRINT TX$;  ' X axis title

LOCATE 8, 1                                        ' Y

FOR J = 1 TO LEN(TY$(PARAM% - 1))                  ' axis
    PRINT MID$(TY$(PARAM% - 1), J, 1)              ' title
NEXT J

LOCATE 25, 10: PRINT "1";                          ' curve
LINE (90, 195) - (130, 195)
LOCATE 25, 20: PRINT "2";                          ' labels
    FOR J = 0 TO 40 STEP 8
        XX = 170 + J
        PSET (XX, 195)
        CIRCLE (XX + 80, 195) , 2
NEXT J
LOCATE 25, 30: PRINT "3";
RETURN
```

```
'****************************************************************************
******************
'*                          PLOTTING ROUTINE                              *
'****************************************************************************
******************
'
1110 FOR J = 1 TO NP
        XX = 580 * DTA(I, J, 1) / MAXX + 60' calculate pixel X position
        YY = 170 - 160 * (DTA(I, J, PARAM%) - MINY) / (MAXY - MINY)


        IF J = 1 THEN GOTO 1170
        IF I = 1 THEN LINE (XXOLD, YYOLD) - (XX, YY) ' line 1170
1170    XXOLD = XX: YYOLD = YY
        IF I = 2 THEN PSET (XX, YY)                    ' point
        IF I = 3 THEN CIRCLE (XX, YY), 2               ' circle
     NEXT J

    RETURN

    END SUB

REM $STATIC
DEFSNG I-L, N
    SUB PRINTS

    '******************************************************************
    '         SUBROUTINE PRINT TO SCREEN AND FILE      *
    '******************************************************************
    ACMDG = 57.3 * ACMD
    ALF = 57.3 * ALPHA
    GAM = 57.3 * GM
    PITCH = ALF + GAM
    WZX = 1.689 * WZ
    IF NOSAVE = 0 THEN PRINT #2, SEC, ALT, HDOT, VT, ALF, GAM, PITCH,
GREFF, WXDT, WZX, VDOT, WSALERT%
    FMT1$ = "###.## #### ##### ### ###.# ###.# ###.# ##.# ###.# ###.# ###.#
#"
    PRINT USING FMT1$; SEC, ALT, HDOT, VT, ALF, GAM, PITCH, GREFF,
WXDT, WZX, VDOT, WSALERT%

    END SUB

SUB RATES STATIC
```

```
'*******************************************************************
'                    SUBROUTINE RATES                    *
'*******************************************************************
SNGM = SIN(GM): CSGM = COS(GM): SNAL = SIN(ALPHA): CSAL =
COS(ALPHA)
VDOT = G * ((THRST * CSAL - DRAG) / WG - SNGM) - WXDT * CSGM -
WZDT * SNGM
GDOT = G * ((LIFT + THRST * SNAL) / WG - CSGM) + WXDT * SNGM -
WZDT * CSGM
GDOT = GDOT / VT
HDOT = 101.28 * (VT * SNGM + WZ)
XDOT = VT * CSGM + WX

AWX = VDOT + WXDT * CSGM + WZDT * SNGM          'Inertial Acc.
along Wind_x axis
AWZ = VT * GDOT - WXDT * SNGM + WZDT * CSGN 'Inertial Acc. along
Wind_z axis

AU = (AWX * CSAL + AWZ * SNAL) / G              'LONG. ACCEL. -
>=?
AZ = (AWX * SNGM + AWZ * CSGM) / G              'VERT. ACCEL.
UP=?

VG = XDOT
GRND = (VT * GM + WZ) / (VT + WX)               'Gamma w/r ground
KF1 = 1
GHAT = GMIN * (1 + WX / VT)
IF WZ > -30 AND WZ < -20 THEN KF1 = 1 + .025 * (WZ + 20)
IF WZ <= -30 THEN KF1 = .75
DGAM = 57.3 * (20 * GDOT - (GHAT - GRND + (1 - KF1) * WZ / 152 +
20 * GDOT))

IF DGAM < 0 THEN
    KF2 = (2 + .4 * DGAM)
ELSE
    KF2 = 2
END IF

IF KF2 < 0 THEN KF2 = 0
KF2 = KF2 / 57.3

END SUB

SUB TAKEOFF STATIC
```

```
'*******************************************************************
'              SUBROUTINE  INTIALIZE  TAKEOFF                      *
'*******************************************************************
IF  APPFLG%  =  0  THEN
                    ALPHA  =  .12
                    WHILE  (LIFT  <=  WG)
                          CALL  DRAGS
                          ALPHA  =  ALPHA  +  .01
                    WEND
                    GM  =  (THRST  -  DRAG)  /  WG      'COMPUTE
POTENTIAL  GAMMA
               ELSE
                    GM  =  -3  /  57.3
                    ALPHA  =  2  /  57.3
                    CALL  DRAGS
                    TFCT  =  1
                    CALL  THRUST
                    T  =  DRAG  -  .052  *  WG
                    IF  T  <  0  THEN  T  =  .2  *  THRST
                    TFCT  =  T  /  THRST
                    THRST  =  T
END  IF
GMO  =  GM
CALL  RATES
END  SUB

SUB  THRUST  STATIC

'*******************************************************************
'              SUBROUTINE  EPR/THRUST                              *
'*******************************************************************
'       TAKE-OFF  THRUST  FOR  JT8D-17  ENGINES
VE  =  1.668  *  VT

R00  =  14688.74:  R01  =  -.65187546#:  R02  =  6.7371E-05
R10  =  -13.9295:  R11  =  .000751143#:  R12  =  -1.5405E-07
R20  =  .014643:  R21  =  5.3444E-07:  R22  =  -4.8907E-10

AA0  =  (R02  *  ALT  +  R01)  *  ALT  +  R00
AA1  =  (R12  *  ALT  +  R11)  *  ALT  +  R10
AA2  =  (R22  *  ALT  +  R21)  *  ALT  +  R20

THRST  =  2  *  ((AA2  *  VT  +  AA1)  *  VT  +  AA0)          'Temp.  =  100  F
```

```
      IF APPFLG% = 1 THEN
                              IF LC% = 1 AND TFCT < 1 THEN
                                                                  GMO = .136
                                                                  TSPL = 5.5
'Engine Spool Up Time
                                                                  TFCT =
TFCT + DT / TSPL
                              END IF
                              IF TFCT > 1 THEN TFCT = 1
                        ELSE
                              TFCT = 1
      END IF
      THRST = TFCT * THRST
"           THRST = 2 * (((2.64159E-05 * VT + 5.110896E-03) * VT - 12.56476) *
VT + 15550)
END SUB

SUB VSHAKER STATIC

      '---------------------------------- COMPUTATION OF Vss AND V2----------------------
--
      V2 = 145
      VTO = V2 + 10'                SETS INITAL SPEED EQUAL TO V2 + 10

      SELECT CASE FLPS%

      CASE 10
            IF VTO < 150 THEN VTO = 150           ' TAKEOFF
      CASE 18
            IF VTO < 148 THEN VTO = 148           ' FLAP
      CASE 22
            IF VTO < 147 THEN VTO = 147           ' SETTINGS

      CASE 33
            VTO = 63.11225 + .222468 * WG / 1000          ' APPROACH
      CASE 42                                             ' FLAP
            VTO = 62.67386 + .21744 * WG / 1000           ' SETTINGS

      CASE ELSE

      END SELECT

END SUB

SUB WINDS STATIC
```

```
'*****************************************************************
'                  SUBROUTINE  WINDS                    *
'*****************************************************************
'
IF  TDX  >  0  THEN
                        T1  =  4
                        T2  =  TSH
                        T3  =  T1  +  T2
                        T4  =  -4
                        T5  =  T3  +  TDX
                        T6  =  T5  -  T4

                        B1  =  3  *  WXDTO  /  T1  ^  2
                        A1  =  -2  *  B1  /  (3  *  T1)
                        B2  =  3  *  WXDTO  /  T4  ^  2
                        A2  =  -2  *  B2  /  (3  *  T4)

                        IF  SEC  >  T2  AND  SEC  < =  T3  THEN
                                                      X  =  SEC  -  T2

                                                            WXDT  =
(A1  *  X  +  B1)  *  X  *  X
                        END  IF

                        IF  SEC  >  T5  AND  SEC  < =  T6  THEN
                                                            X = SEC - T6

                                                            WXDT = (A2
*  X  +  B2)  *  X  *  X

                        END IF

                        IF  SEC  >  T6  THEN  WXDT  =  0

                        WX  =  WX  +  WXDT  *  DT
END  IF
IF  TDZ  >  0  THEN
                  T1  =  4
                  T2  =  TSV
                  T3  =  T1  +  T2
                  T4  =  - 4
                  T5  =  T3  +  TDZ
                  T6  =  T5  -  T4
```

```
                B1 = 3 * WZO / T1 ^ 2
                A1 = -2 * B1 / (3 * T1)
                B2 = 3 * WZO / T4 ^ 2
                A2 = -2 * B2 / (3 * T4)

                IF SEC > T2 AND SEC <= T3 THEN
                                X = SEC - T2
                                WZ = (A1 * X +
B1) * X * X
                                WZC = WZ

                END IF

                IF SEC > T5 AND SEC <= T6 THEN
                                X = SEC - T6
                                WZ = (A2 * X +
B2) * X * X
                                WZC = WZ
                END IF

                KALT = (-.0000011 * ALT + .00212) * ALT - .0251

                IF KALT < 0 OR ALT <= 0 THEN KALT = 0
                KALT = 1
                WZ = KALT * WZC

                IF SEC > T6 THEN WZ = 0

                WZDT = (WZ - WZ1) / DT
                WZ1 = WZ
    END IF

    IF DFW = 1 THEN CALL MCRBRST            'DALLAS Model

END SUB

^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z^Z
```